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# LETTERS TO THE EDITOR

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## A Possible Explanation of the Frequency Distribution of Sizes of Hoffmann Stösse

The cloud chamber photographs of Blackett and Occhialini, Anderson, and Locher[1] have brought to light the suggestion that Hoffmann Stösse may not originate in a single atom, but may arise from several atoms as the result of a primary cosmic ray acting through intermediaries. Each of these observers finds groups of ray tracks, apparently all formed simultaneously. These tracks are possibly produced by the particles which give rise to the bursts of ions observed in a pressure chamber. However, these tracks do not diverge from a common point, but seem, in many cases, to be formed in several groups, each group of tracks diverging from a separate point. The existence of these multiple centers has been attributed by Locher[1] to the action of neutrons which, coming from any one nuclear disintegration, serve to precipitate others. Experiments by W. F. G. Swann and the author are in progress at the present time for the purpose of testing this conclusion further and particularly to ascertain whether the size of a Stoss depends upon the amount of material involved.

Data showing the frequency of occurrence of Stösse of different sizes have been published by Steinke and Schindler, and by Messerschmidt[2] and similar data have been taken at the Bartol Foundation with an apparatus which has been previously described.[3] These data all show the surprising fact that although a greater portion of the Stösse is grouped around a definite size, Stösse ten times this size occur fairly often. The object of the present note is to show how the cooperation of several atoms in the production of a Stoss would give rise to such a frequency distribution of Stoss sizes as is observed.

Let us suppose we have a block of material placed over an ionization chamber and suppose a group of rays is formed near the top of the block. These rays will contain among them entities capable of producing other groups and such secondary groups will be produced within the block. If the ranges of the ionizing rays are greater than the thickness of the block, then rays from both the primary and secondary groups will reach the ionization chamber and be recorded. Thus, on the average, if the primary group is formed near the top of the block of material, the number of ionizing rays which penetrate the ionization chamber will be larger than if the primary group is formed near the bottom of the block. Then the recorded Stösse will consist of a whole range of sizes similar to the observed range.

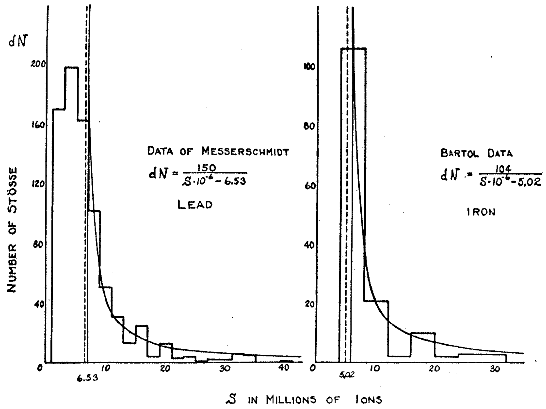

FIG. 1. Observed and computed distributions of sizes of Stösse.

We can put the matter into a more quantitative form and obtain a rather good agreement with the observed distribution curves if we make a few simplifying assumptions. Let us suppose that the primary group will produce $p$ ions in the chamber, and that $p$ is independent of the position of the origin of the group. Also let us suppose that the rays of the primary group will produce a secondary group of size $s$ ions, on the average, every $a$ centimeters. Further let us suppose that each secondary group also produces groups of size $s$ every $a$ centimeters, and so forth. Then, if the primary group is formed at a distance $r$ from the top of the block of material of thickness $D$, the size[4] of the resultant Stoss will be

$$S = p + s(2^{(D-r/a)} - 1). \qquad (1)$$

Let us assume that the number of primary groups formed

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[1] P. M. S. Blackett and G. Occhialini, Proc. Roy. Soc. Lond. **A139**, 699 (1933); C. D. Anderson, Phys. Rev. **43**, 368 (1933); G. L. Locher, Phys. Rev. **44**, 779 (1933).

[2] E. Steinke and H. Schindler, Zeits. f. Physik **75**, 115 (1932); W. Messerschmidt, Zeits. f. Physik **78**, 688 (1932).

[3] W. F. G. Swann and C. G. Mongtomery, Phys. Rev. **44**, 52 (1933).

in the element of thickness $dr$ is independent of $r$, then we can write $dN=kdr$ where $k$ is a constant. From relation (1), we obtain

$$dS=-(\log 2/a)[S-(p-s)]dr$$

or

$$dr=-a\,dS/\{\log 2[S-(p-s)]\}.$$

Then the form of the distribution curve will be given by

$$dN=-\frac{ak/\log 2}{S-(p-s)};\quad dS=-\frac{A}{S-b}\,dS.$$

This depends on only two parameters, and we may fit it to the observed distribution curves. The data of Steinke and Schindler are unsuitable for consideration in the present connection since they give a distribution curve for the difference in size of Stösse occurring simultaneously in two chambers placed side by side. However, we can compare Messerschmidt's results and those obtained at the Bartol Foundation with this empirical formula. The accompanying curves show how well this elementary theory fits the observations. For Messerschmidt's data, we obtain $A=75$, $b=6.53\times 10^6$ ions, and for the Bartol data $A=26$, $b=5.02\times 10^6$ ions. $b$ represents the difference in size of a primary and a secondary group, while $A=ak/\log 2$, where $k$ is the total number of primary groups per centimeter. Since the observations do not extend to sufficiently small sizes, we can only set a lower limit to it. For the Bartol data, $D=2.5$ cm iron, $k>59$ and hence $a<0.3$ cm. For Messerschmidt's data, $D=10$ cm lead, $k>81$ and $a<0.6$ cm.

We see that the observed curves, in their middle range at least, are well represented by such a picture of the Stoss-forming process as is given here. The deviations at either end are certainly to be ascribed to the overly simplified picture used. An elaboration of the theory would involve a closer specification of the probabilities of formation of the secondary groups, rather than the assumption that they are all equal. Although this would improve the agreement, it would only tend to complicate the calculations and would add nothing to the picture of the mechanism. However, the agreement is certainly good enough to regard the model used as a fair approximation to what actually happens. It is to be noticed that the essential idea in the process is that all groups, whether primary or secondary, are capable of producing other groups. The application of the picture of a primary group producing secondary groups all along its path ($S$ in this case would vary linearly with $r$) is not capable of giving a distribution curve of the type observed.

The real importance of this picture of the formation of Stösse lies in the predictions that can be made from it. First, there should be a lower limit to the sizes of Stösse, and this limit is the size of the primary group of rays. If an upper limit of size exists, it probably depends upon the energy of the primary cosmic ray. Second, the distribution curves of Stoss sizes will depend upon the thickness of the material from which the Stösse come: thicker materials should give larger Stösse. There should also be observed "transition" effects if there is a primary or secondary Stoss size characteristic of the material. The lower limit of the size should, however, be dependent only upon the last material through which the Stoss particles pass.

In conclusion, the author wishes to express his thanks to Dr. W. F. G. Swann for his helpful encouragement and discussion of the ideas involved here.

C. G. MONTGOMERY

Bartol Research Foundation
of The Franklin Institute,
November 26, 1933.

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[4] The "2" in this expression results from the assumption that the number of groups doubles every "$a$" centimeters. As Dr. Swann has pointed out to the author, if the number of groups is derived by an integration process, the "2" becomes an "$e$."

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## Gamma-Rays from Lithium Bombarded with Protons

In a previous letter to the *Physical Review*[1] we reported the production of neutrons by the bombardment of lithium chloride with hydrogen ions. The measurements were made with an ionization chamber lined with paraffin and enclosed in a lead cylinder of 5 cm wall thickness. That the ionization was, in part at least, due to neutrons was concluded from the observation that less ionization was observed when the paraffin was removed from the chamber. We observed, however, that the difference in ionization with and without paraffin was in this case less than in the measurements of neutrons produced by other disintegrations previously investigated by us. This suggested that in the case of lithium a considerable part of the ionization might be due to $\gamma$-rays.

It is well established that lithium when bombarded with protons yields a group of long range $\alpha$-particles and one or more groups of shorter range. Oliphant, Kinsey and Rutherfore[2] have recently made very careful measurements of the ranges and numbers of these particles and have found ranges of 0.65, 1.15 and 8.3 cm, the relative numbers of which are 0.5, 1 and 1, respectively. The 8.3 cm particles are satisfactorily accounted for by the reaction $Li^7+H^1\rightarrow 2He^4$, but this does not explain the two short range groups observed, unless the excess energy (about $12\times 10^6$ e.v.) goes into a $\gamma$-ray. A search for such $\gamma$-rays has been made by Traubenberg, Eckartt and Gebauer,[3] but the evidence is not very conclusive. It is clear, therefore, that if all of these particles result from the disintegration of $Li^7$ with protons, the process must be more complicated than indicated by the above equation.

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[1] Crane and Lauritsen, Phys. Rev. **44**, 783 (1933).

[2] Oliphant, Kinsey and Rutherford, Proc. Roy. Soc. **A141**, 722 (1933).

[3] Traubenberg, Eckartt and Gebauer, Zeits. f. Physik **80**, 557 (1933).