Distribution of Cosmic-Ray Nuclear Disintegration in Time

In connection with the investigations of W. F. G. Swann and the authors on nuclear disintegrations produced by cosmic rays,[1] the question arose as to whether these disintegrations occurred individually and collectively at random in time. To test this, observations were taken for a thirty-five hour period with the large ionization vessel and recording system previously described. The time intervals between the occurrence of bursts of ionization larger than four million ions in nitrogen at a pressure of 100 pounds per square inch were measured, and the number of intervals between certain limits were obtained. These data were compared with the numbers to be expected by the method used by Marsden and Barratt[2] for alpha-particles. If n is the number of intervals and τ is the average interval, then n is given by

$$n = N(e^{-t_1/\tau} - e^{-t_2/\tau}).$$

TABLE I.

t_1 (sec.)	t_2 (sec.)	n calculated	n observed	difference r	divergence $r^2/n_{\text{calc.}}$
0	50	19.38	22	+1.62	0.14
50	100	17.89	17	−0.89	0.04
100	200	30.46	26	−4.46	0.65
200	500	63.47	68	+4.53	0.32
500	1000	50.48	47	−3.48	0.24
1000	2000	26.62	31	+4.38	0.72
2000	5000	4.69	2	−2.69	1.54
5000	∞	0.01	0	0	
Totals		213.00	213	$\chi^2 = 3.65$ $\tau = 521.6$ sec.	

The agreement between these expected numbers and the observed ones can be seen from Table I. The fit between the observed and calculated values has been measured by Pearson's criterion and the value of χ^2 obtained is given in the last column. From distribution tables of χ^2 we find[3] that the probability of a divergence greater than this is between 0.7 and 0.5. Thus the data are in good accord with the hypothesis that the nuclear disintegrations observed are randomly distributed in time.

The authors wish to express their thanks to Dr. W. F. G. Swann for his enthusiastic support.

C. G. MONTGOMERY
D. D. MONTGOMERY

The Bartol Research Foundation
of the Franklin Institute,
October 5, 1933.

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[1] W. F. G. Swann and C. G. Montgomery, Phys. Rev. **44**, 52–53 (1933).

[2] Marsden and Barratt, Proc. Phys. Soc. **23**, 367 (1911); **24**, 50 (1911); Rutherford, Chadwick and Ellis, *Radiations from Radioactive Substances*, p. 172, Cambridge, 1930.

[3] T. C. Fry, *Probability and its Engineering Uses*, p. 468, New York, 1928.

Neutrons from Cosmic-Ray Stösse

Some preliminary results of the cloud photography of cosmic-ray Stösse, or ionization bursts, in argon, seem sufficiently interesting to be described here. Numerous neutron-recoil atom tracks, two long nucleus tracks, and groups of simultaneous tracks that converged at different points, were found.

A cloud chamber 15 cm in diameter has been arranged to be set off immediately after the simultaneous discharge of 3 Geiger-Müller cosmic-ray counting tubes, placed with two above and one below the chamber, but as far *out of line* as possible. The principle of its operation is similar to that of the apparatus of Blackett and Occhialini,[1] except that the counters are not set off by single rays. Of the triple-coincidence counting rate, 1.26 hr.$^{-1}$, it is estimated from the photographs taken that about one-third of the discharges are from Stösse and two-thirds from branched tracks, double tracks, and so on. Surrounding the chamber are 1350 lb. of massive material, consisting of 750 lb. of lead, 400 lb. of copper and brass, and 200 lb. of iron. A cloud atmosphere of argon at 64.5 cm pressure is used. The specific ionization of tracks in argon is high; the relatively high viscosity makes the tracks persist better than tracks in air; the expansion ratio is small (1.18, as compared with 1.3 for air), and the probability of obtaining recoil atoms from any neutrons present is relatively high. Since the ionizing particles traverse the chamber about 0.01 sec. before the expansion, the tracks are somewhat diffused by thermal agitation and the expansion; equality of diffuseness of tracks of like densities serves to establish approximate simultaneity of their formation, and makes it easy to discriminate between pre- and post-expansion tracks.

Figs. 1, 2, and 3 are stereophotographs of interesting

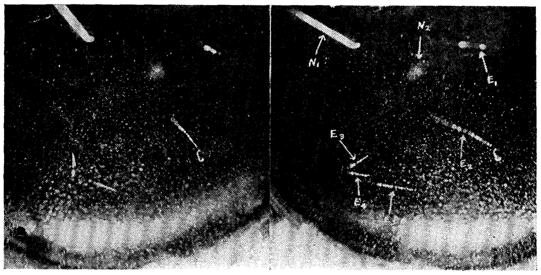

FIG. 1. Stoss with 2 nucleus tracks (N), and 5 electron tracks (E). E_1, E_2 and N_1 converge at a point in the lead, above and behind the chamber. E_3, E_4 and E_5 converge at another point. N_2 is believed to be an argon atom recoiling after elastic collision with a neutron. The heavy nucleus track, N_1, ends in the chamber with a sharp bend. (Mag. ×0.35)

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[1] Blackett and Occhialini, Proc. Roy. Soc. (London) **A139**, 699 (1933).

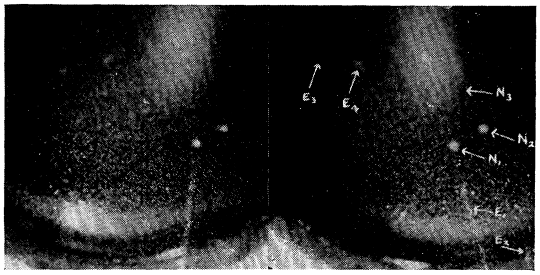

FIG. 2. Stoss with 4 electron tracks, 2 neutron-recoil tracks, N_1 and N_2, and a long, diffuse nucleus track, N_3, near the bottom of the chamber. (Mag. ×0.35)

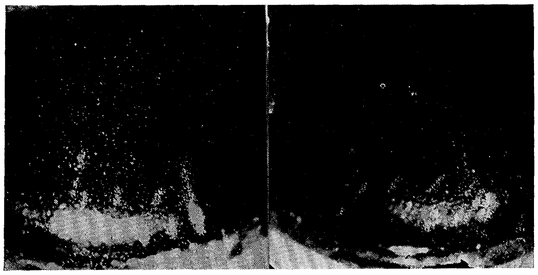

FIG. 3. Stoss with 13 tracks of the same "age." Eleven of these converge in a lead block about 40 cm above and in front of the cloud chamber; the other two appear to be secondary branches originating in the glass lid of the cloud chamber. (Mag. ×0.35)

Stösse; Figs. 4, 5, and 6 are single photographs of three others. Conspicuous features found in nearly every burst photographed are the non-convergence to a single point of the (simultaneous) tracks of each burst, and the presence of very short nucleus-tracks in the gas, which closely resemble the recoil-atom tracks formed by beryllium neutrons in argon. Blackett and Occhialini[1] mention cases of showers emanating from more than one point, and Anderson[2] has photographed a shower showing the same characteristic.

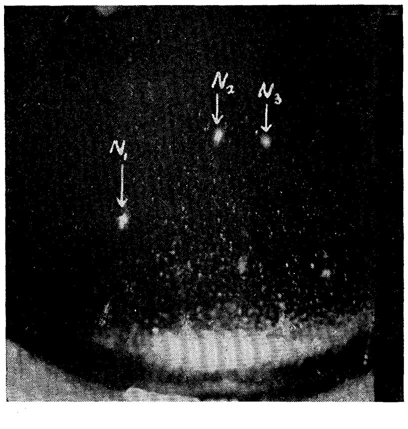

FIG. 4. Stoss with 15 tracks: 11 simultaneous pre-expansion electron tracks, 3 neutron-recoil argon atoms, N_1, N_2 and N_3, and a post-expansion electron track. Most of the electron tracks traverse the chamber in nearly vertical directions, but could not have come from less than 4 points of convergence. (Mag. ×0.53)

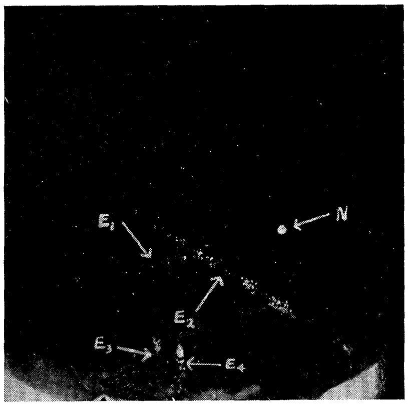

FIG. 5. Four electron tracks of the same age, and a neutron-recoil argon atom, N, E_1 and E_2 do not intersect; E_3 and E_4 seem to intersect in the iron of the arc used for illumination. (Mag. ×0.53)

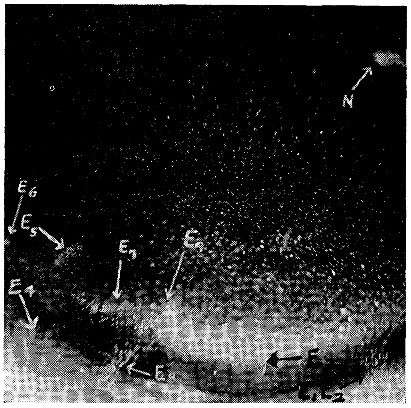

FIG. 6. Stoss with at least 9 electron tracks and one nucleus track, N. E_1 and E_2 are nearly horizontal and in line with the arc; E_3, E_4, and E_5 are nearly parallel and vertical; E_7, E_8 and E_9 diverge upward from a point near the bottom of the chamber. N is believed to be neutron-recoil nucleus; it is somewhat out of focus, and appears larger than it really is. (Mag. ×0.53)

If we postulate that each burst derives its energy from a *single* primary entity, *we must suppose that the primary entity generates secondaries that are extremely efficacious in setting up tertiary centers of disruption*, since the tertiary track-foci are relatively close together. From the evidence so far available, it seems improbable to the writer that the secondary entities are photons. The necessarily high energies of such photons would be incompatible with the ob-

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[2] Anderson, Phys. Rev. **43**, 368 (1933).

served facility of their absorption by matter near the cloud chamber, unless their numbers were so very great as to impose excessive requirements on the energy drawn from the primary entity. On the other hand, it seems reasonable to expect that some low-energy quanta, at least, are set free from Stösse. Against the possibility that the secondary agents are ionizing particles, is the fact that on no picture was there a track *observed* which linked two track-foci together. Photographs of additional bursts will doubtless help to clarify the question of the nature of these secondary entities that react with nearby matter by starting new disintegration points.

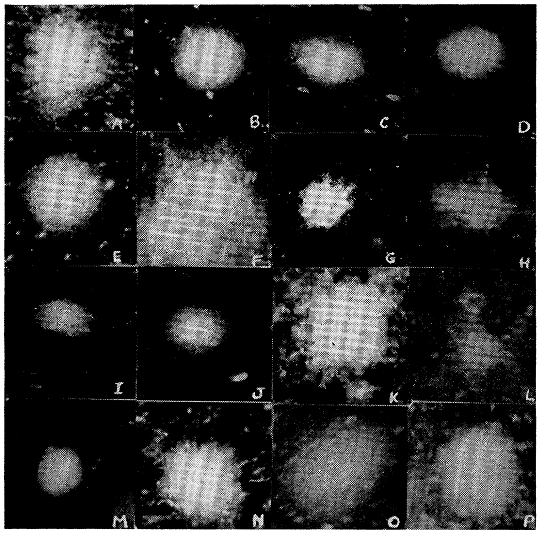

FIG. 7. *A* through *J*, short nucleus tracks from cosmic-ray Stösse photographs, attributed to argon atoms recoiling from elastic collisions with neutrons emitted from the Stösse. *K* through *P*, recoil-atom tracks formed in the same atmosphere, but with beryllium neutrons from a Po–Be source. The energies of the atoms of the two groups are of the same order of magnitude. (Mag. ×2.8)

Fig. 7 shows microphotographs of some of the short recoil-atom tracks from Stösse, also some recoil-atom tracks from Be neutrons, in the same cloud atmosphere, for comparison of ionization density and energy. The similarity is very evident. Tracks of this kind are recognizable with considerable certainty because of the enormous density of their ionization. The use of argon greatly facilitates the detection of neutrons; Bonner[3] has found from ionization measurements that the target area of the argon atom for Be neutrons is about 17 times that of hydrogen or 4.85 times that of nitrogen. Since the tracks of the Stösse do not converge to single points, it is impossible to tell from what material the neutrons arise, but the infrequency of appearance of recoil atoms on pictures other than those of Stösse indicates that the neutrons somehow arise from disintegration processes. The numbers of short recoil-atom tracks from Stösse is about the same as the number of Be neutron-recoil atom tracks from a Be–Po source of 0.05 millicurie radium equivalent, placed on top of the cloud chamber, or 1 to 10 millicuries at the Stoss track-foci. But the energy and ionization characteristics of the Stoss-neutrons are unknown, so that comparison of their number with those of Be neutrons is little more than speculation.

The secondary agents responsible for ejecting the convergent groups of tracks found in Stösse are still unidentified. If the low-energy recoil tracks observed are produced by high-energy neutrons, the latter *might* satisfy the difficult requirement of an agent having high energy and producing numerous subsidiary points of disintegration within a small region. But this hypothesis is based rather on our *lack* of knowledge of the energy-dissipation properties of such neutrons than on our knowledge of them.

These experiments are being continued with masses of aluminum about the chamber, in place of lead, in order to determine whether the heavier ionization produced by Al-Stösse[4] results from the generation of nucleus tracks or more numerous electron tracks.

The writer is indebted to Dr. W. F. G. Swann for suggesting the cloud-photography of Stösse, and for his discussion of the subject.

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Bartol Research Foundation
of the Franklin Institute,
October 7, 1933.

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[3] Bonner, Phys. Rev. **43**, 871 (1933).

[4] Steinke, Gastell and Nie, Naturwiss. **21**, 560 (1933).

* National Research Fellow.

Neutrons from Deutons and the Mass of the Neutron

Last spring we directed 1.2 MV (million volt) deutons against many different targets and in every instance observed the production of 18 cm (3.6 MV) protons.[1] The most reasonable interpretation of the observations seemed to be that the deuton itself was disintegrated as a result of nuclear collisions with atoms of the various targets.

It was observed also (except in the case of gold where the observations were meager) that when the energy of the bombarding deutons was changed, the energy of the disintegration protons changed an equal amount, indicating that all of the kinetic energy of the deuton was acquired by the proton alone. Thus it appeared that the deuton has by far the greatest probability of disintegrating when it is nearest another nucleus and that the liberated proton gains in the process 2.4 MV in addition to the kinetic energy of the deuton. Assuming that the interaction of the liberated neutron with the heavier nucleus is negligible, it follows from the principle of conservation of momentum that the neutron acquires 2.4 MV of kinetic energy. Thus, 4.8 MV

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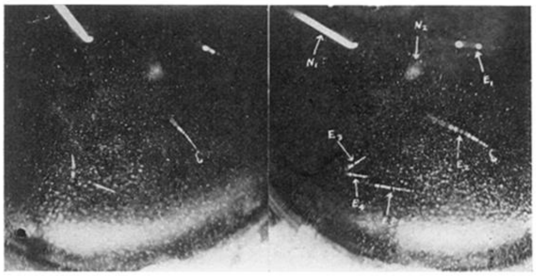
[1] Lawrence, Livingston and Lewis, Phys. Rev. **44**, 56 (1933).



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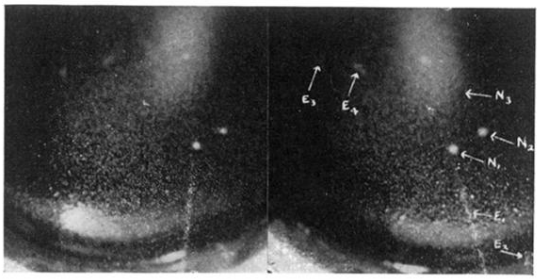

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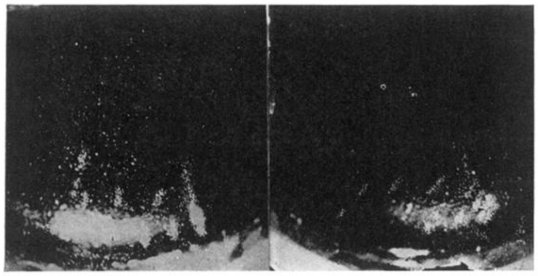

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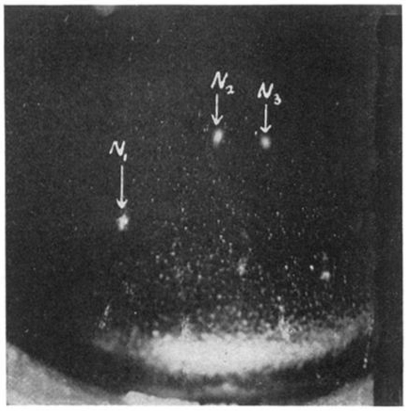

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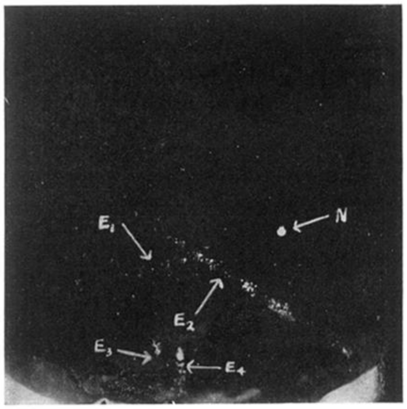

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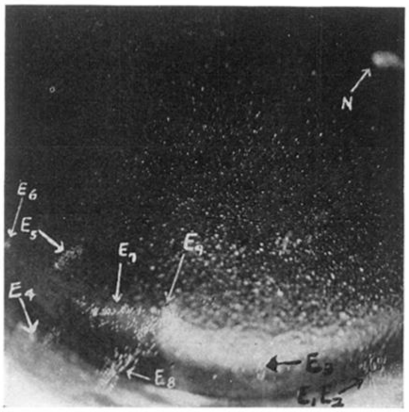

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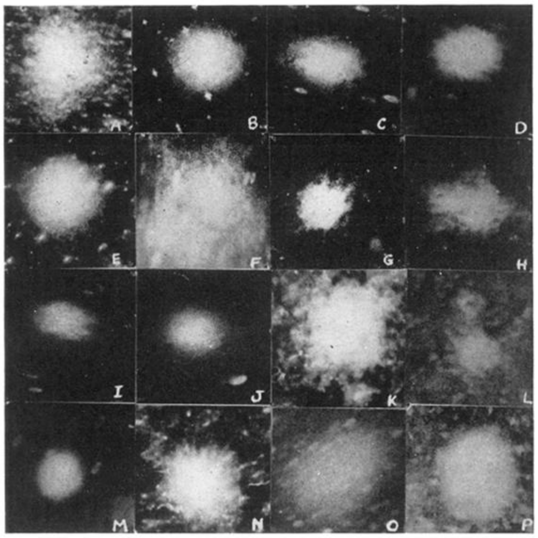

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