The Scattering of Protons in Collisions with Neutrons

The scattering of protons and neutrons in their collisions with each other is of importance in connection with one of the most fundamental problems of physics—the nature of the neutron and of the proton, and their relationship to each other and to the negative and the positive electron. The neutron, an atom of zero atomic number,[1] may consist of a proton and a negative electron

$${}_0^1n_1 \rightarrow {}_1^1p_{-1} + {}_{-1}^0e_2$$

as is in agreement with the Harkins[2]-Heisenberg[3] theory of the general composition of atomic nuclei, or a proton may consist of a neutron and a positive electron

$${}_1^1p_{-1} \rightarrow {}_0^1n_1 + {}_1^0e_{-2}.$$

On either basis the collision between a proton and a neutron gives a problem similar to that related to H_2^+. There may be scattering, or a deuteron may be formed.

On this basis a neutron-proton exchange reaction is involved, as well as the possibility that in some collisions deuterons are formed.[4] The scattering should be affected by this exchange.

A new neutron source is now being prepared in this laboratory, and this is to be used under conditions which should lead to a better solution of the neutron-proton collision problem. Measurements of the angle θ between the direction of the proton and that of the neutron before impact, have been made for 426 neutron-proton collisions with somewhat larger, and therefore less suitable neutron sources.

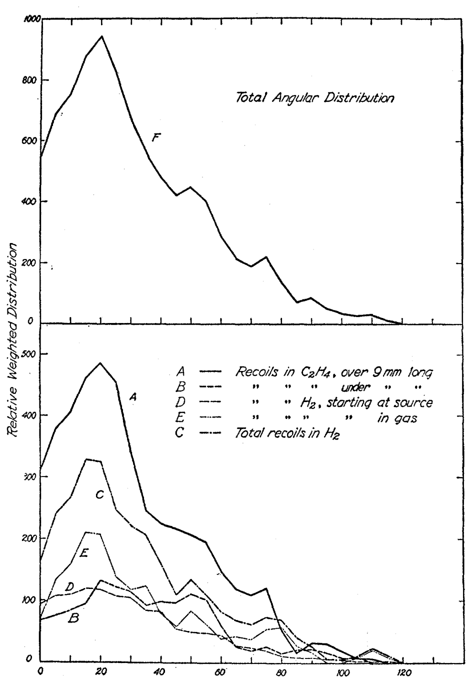

FIG. 1.

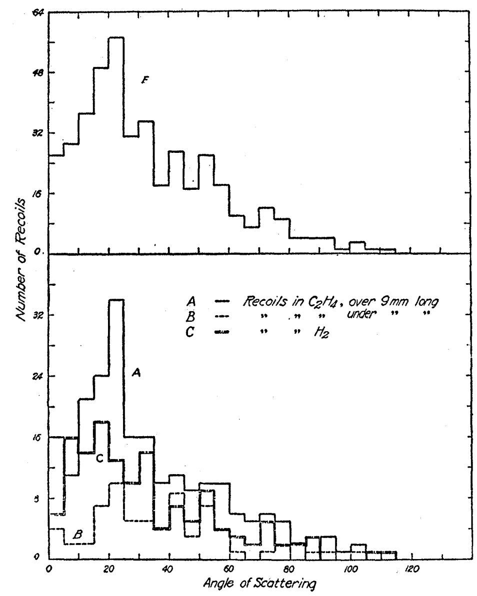

FIG. 2.

For elastic spheres of equal mass the scattering is a maximum at 45°, while Fig. 1 exhibits a maximum at a value of about 20° for θ, the angle between the initial direction of the neutron, and the direction of the proton. For the spheres the distribution is uniform in all directions to an observer at the center of gravity of the system, so that if equal intervals in the value of cos 2θ are taken the number (N) is constant. This is not true for Table I which presents the data of Fig. 1 in this modified form.

TABLE I. *Number* (N) *of proton tracks per 1000 in each interval of 0.1 in* cos 2θ.
(θ_2 is the value of θ at the end of the interval.)

θ_2	N	θ_2	N	θ_2	N	θ_2	N
12.9	213	33.2	48	47.9	29	63.5	22
18.4	115	36.2	41	50.8	30	67.2	18
22.8	94	39.2	37	53.8	30	71.6	20
26.5	71	42.1	33	56.8	25	77.1	27
30.0	59	45.0	30	60.0	24	90.0	32

To the observer at the center of gravity 770 proton tracks are projected forward and 230 backward. The values of N for the first seven intervals of 0.05 in cos 2θ are 141, 72, 61, 54, 44, 38, 33. Auger[5] and Meitner[6] obtain a scattering which agrees with that for elastic spheres, while that obtained by Kurie[7] is somewhat similar to, though not the same as that found in our experiments.

Fig. 2 gives the number of recoil protons obtained for each interval of 5° in the value of the angle (θ) of scattering.

The values of Fig. 1 were weighted. The neutron source was beryllium mixed with mesothorium for the work in ethylene, and this plus thorium X for that in hydrogen. The diameters of the sources were about 6 mm in ethylene and 4 mm in hydrogen. To each collision a spread in scattering angle was attributed. This was equal to the angle subtended at the point of impact by a sphere 8 mm in diameter. This makes some allowance for the fact that around the source there was a hemispherical wall of platinum 0.5 cm thick, used to keep x-rays from the chamber, and thus produces some scattering.

The number of points at which the neutron-proton collisions occurred was found to be very nearly proportional to the inverse square of the distance.

William D. Harkins
David M. Gans
Martin Kamen
Henry W. Newson

University of Chicago,
February 25, 1935.

[1] *W.* D. Harkins, J. Am. Chem. Soc. **42**, 1956 (1920); E. Rutherford, Proc. Roy. Soc. **A97**, 374 (1920).
[2] W. D. Harkins, J. Am. Chem. Soc. **43**, 1038 (1921); W. D. Harkins and S. L. Madorsky, Phys. Rev. **19**, 139 (1922).
[3] W. Heisenberg, Zeits. f. Physik **77**, 1 (1932).
[4] E. Wigner, Zeits. f. Physik **83**, 253 (1933). The writers have discussed this with Professor Guido Beck.
[5] P. Auger and G. Monod-Herzen, Comptes rendus **196**, 1102 (1933).
[6] L. Meitner and K. Philipp, Zeits. f. Physik **87**, 484 (1934).
[7] F. N. D. Kurie, Phys. Rev. **44**, 463 (1933).

The Enhancement of Cosmic-Ray Nuclear Bursts by the Presence of Subsidiary Material

It has been pointed out[1, 2] that cloud-chamber photographs of showers of rays strongly suggest that a shower contains radiation which has the power of creating another shower. Hence it should be possible for the radiation accompanying a shower formed in one body to produce a shower in another body. An experiment to show this phenomenon has been performed. As the first body the water contained in a tank 126 cm in diameter and 150 cm high was employed. Seventy-five centimeters below the tank was placed the second body: a spherical ionization chamber of cast steel of 2.5 cm wall thickness and 14.2 liters capacity, filled with nitrogen to a pressure of 12.5 atmospheres. The number of bursts of ionization greater than 0.45×10^6 ions occurring in the chamber was measured for different thicknesses of water. As the depth of the water was increased, the number of bursts first increased, so that at a thickness of 79 cm of water, the number was about 20 percent greater than at zero thickness. At still greater depths of water, the number of bursts decreased, until, at 136 cm, approximately as many bursts were observed as at zero thickness. This is represented by the center curve of Fig. 1. Some observations were also taken with a slightly higher sensitivity in which bursts greater than 0.35×10^6 ions were measured. The increase between zero and 41 cm of water for these bursts is shown in the upper curve of the figure.

At first glance, the simplest interpretation of these data would seem to be that the additional bursts observed when water was present were bursts of ionizing rays originating in the water and passing through the walls of

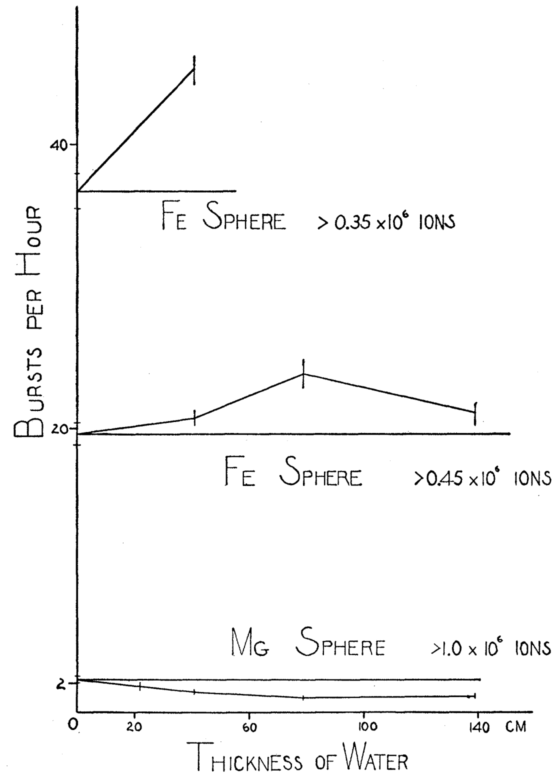

Fig. 1. The rate of occurrence of bursts of ionization in chambers placed below different thicknesses of water. The vertical lines at the observed points represent the standard deviation in the rate computed from the square root of the number of bursts observed.

the ionization chamber despite the large intervening thickness of water and iron. However, when an ionization chamber with one centimeter magnesium walls was substituted for the steel one, the number of bursts decreased uniformly as the depth of the water was increased. These data are shown in the lower curve in the figure. The magnesium chamber had a volume of fifty liters and was filled with nitrogen to a pressure of 14.5 atmospheres. In order to compare its results with those obtained with the steel chamber, bursts of a somewhat larger size should be considered. The size of burst in the magnesium sphere comparable to 0.45×10^6 ions in the steel chamber is 0.78×10^6 ions if we suppose the ionization per centimeter of path should be the same, and 1.84×10^6 ions if the ionization per unit volume should be the same in the two cases. A value between these two, *viz.*, 1.0×10^6 ions, has been chosen for the purposes of this comparison.

The uniform decrease in the number of bursts observed with the magnesium chamber obviously represents the absorption of the primary burst-producing rays. It is of the order of magnitude to be expected from the variation with altitude of the number of bursts in this chamber.[3] There is no evidence of the three or four bursts per hour coming from the water whose occurrence the data taken