9.0179±0.0009 which Hönigschmid and Birkenbach[6] obtained by chemical means.

(3) The packing fraction of Be^9 is +17.2 which is located well off the packing fraction "curve" for elements of even atomic number.

(4) Curie and Joliot[7] have calculated the mass of Be^9 and obtained a value 9.0109 on the $O^{16}=16$ scale under the assumptions that $Be^9+\alpha \rightarrow C^{12}+$neutron, that the energy of the neutron is 7.8×10^6 electron-volts, that no γ-rays are emitted in the process of disintegration, and that the Be neutrons have the same mass as the B neutrons. On the other hand the work of Meitner and Philipp[8] and of Rasetti[9] in conjunction with that of Becker and Bothe[10] strongly indicates that γ-rays do accompany the emission of neutrons from beryllium when it is bombarded by α-particles. Taking the process of disintegration to be $Be^9+\alpha \rightarrow C^{12}+\text{neutron}+h\nu$ and the mass of Be^9 to be 9.0155 and the mass[11] of the neutron 1.0067, 12.1×10^6 electron-volts are available for the energies of the neutron and γ-ray. Under this mode of disintegration 7.8×10^6 electron-volt neutrons[7] might be accompanied by 4.3×10^6 electron-volt γ-quanta. It is an open question whether the γ-rays found experimentally,[12] are produced as a primary process in the disintegration of the beryllium or whether, as indicated in the recent experiments of Auger,[13] the γ-rays are produced by a secondary process as a result of inelastic neutron impacts in nearby materials. The production of γ-rays by both processes may of course take place concurrently.

(5) Sufficient energy is available from the combination $Be^9+\alpha+E_\alpha$ so that a large number of disintegration mechanisms are theoretically possible. The evidence available at present is best satisfied by the reaction $Be+\alpha \rightarrow C^{12}+\text{neutron}+h\nu$. The experiments which have been performed up to the present time have not been such as to eliminate alternative modes of disintegration. One such possible mechanism, for example, might be $Be^9+\alpha \rightarrow 3\alpha+\text{neutron}+h\nu$, which might be a "capture" or a "non-capture" process.

Although the measured mass of Be^9 cannot be used at present for an evaluation of the mass of the neutron, it is hoped that this Be^9 mass determination may help ultimately in the solution of the questions attendant on the disintegration of beryllium by different agents.

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K. T. Bainbridge

Bartol Research Foundation of the
Franklin Institute,
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[6] O. Hönigschmid and L. Birkenbach, Ber. Chem. Ges. **55B**, 4 (1922). The atomic weight of beryllium from the ratio $BeCl_2/Ag$ is given as 9.0179 with a "mean error" ±0.0013.

[7] I. Curie and F. Joliot, Nature **130**, 57 (1932); I. Curie, F. Joliot and P. Savel, C. R. **194**, 2208 (1932).

[8] L. Meitner and K. Philipp, Naturwiss. **20**, 929 (1932).

[9] F. Rasetti, Zeits. f. Physik **78**, 165 (1932).

[10] H. Becker and W. Bothe, Zeits. f. Physik **76**, 421 (1932).

[11] J. Chadwick, Proc. Roy. Soc. **A136**, 692 (1932). The mass of the neutron is 1.0067±0.0010 from Chadwick's disintegration data and Aston's mass values for N^{14}, B^{11} and He^4 (reference 2). The probable error has been calculated here in the customary manner on the basis that Aston's limits of error are equal to three times the probable errors of his measurements. Two other sets of data permit an upper and a lower limit to be placed on the mass of a neutron, assuming the existence of only one type of neutron.

The emission of neutrons by the process $Li^7+\alpha \rightarrow B^{10}+n$ gives an *upper limit* for the mass of a neutron 1.0063 ±0.0008 from the mass data of J. Costa (Ann. de Physique **4**, 425 (1925)) and F. W. Aston (reference 2) and the disintegration experiments of I. Curie, F. Joliot and P. Savel (reference 7) and M. de Broglie and L. Leprince-Ringuet (C. R. **194**, 1616 (1932)).

If the nucleus of H^2 is composed of one proton and one neutron, 1.0057±0.0002 is a *lower limit* for the mass of a neutron (K. Bainbridge, Phys. Rev. **41**, 115 (1932)).

[12] Wilson chamber β-ray tracks in a magnetic field, I. Curie and F. Joliot, C. R. **194**, 708, 1229 (1932). P. Auger ibid., 877. By absorption and coincidence method, H. Becker and W. Bothe, Naturwiss. **20**, 757 (1932) and reference 10; F. Rasetti, Naturwiss. **20**, 252 (1932).

[13] P. Auger, C. R. **196**, 170 (1933).

Cosmic-Ray Bursts

In cloud-chamber experiments the frequent occurrence of associated tracks has been observed.[1] It has been pointed out that a simple binary collision cannot explain all the associated tracks.[2]

During the course of photographing cosmic-ray tracks in a magnetic field of 15,000 gauss, one exposure was obtained showing a group of twelve tracks. The tracks, which occurred "early," were coincident in time as shown by the fact that the diffusion of the ions broadened all the tracks to the same extent. The individual ions were clearly resolved.

Seven of the tracks are clearly seen to originate at a common point in the upper portion of the chamber, probably in the wall material. There are in addition five tracks which do not come accurately from this point of origin, but do diverge from the same region of the chamber, their directions perhaps having been changed by scattering

[1] Skobelzyn, Zeits. f. Physik **54**, 686 (1929); Auger and Skobelzyn, C. R. **189**, 55 (1929); Locher, Phys. Rev. **39**, 883 (1932); Millikan and Anderson, Phys. Rev. **40**, 325 (1932); Anderson, Phys. Rev. **41**, 405 (1932).

[2] Millikan and Anderson, reference 1; Anderson, reference 1.

in the chamber wall. In this group while the predominant direction is downward, two are ejected upward.

The sense of curvature in the magnetic field for the seven tracks emanating from the point of origin is such as to indicate electrons. The remainder of the tracks with two exceptions must also be ascribed to electrons on the basis of curvature, range and specific ionization. Protons or heavier particles of the degree of curvature observed would have energies too low to be consistent with the observed minimum ranges and specific ionization. The identification of the remaining particles is not possible. They may be either electrons or protons. The bulk of the tracks, however, and perhaps all represent electrons.

The energies in millions of electron-volts of the measurable tracks are: 35, 33, 32, 30, 20, 17, 17, 14, >30, >10. These energies lie well above the known energies of radioactive processes, and are therefore to be attributed to cosmic rays.

Cosmic-ray ion-chamber experiments have shown occasional bursts of ionization, a million and more ions being apparently formed in the gas of the ion-chamber at one time.[3] Millikan and Neher have observed one burst which seems to correspond to the release of 50 million ions. Obviously electrons cannot be the immediate ionizing agents in producing these large ion-chamber bursts since more than 1000 electrons would have to be assumed to traverse the ion-chamber simultaneously to account for some of them. Heavier nuclear constituents of lower range and greater specific ionization can, however, be called upon to explain the larger effects.

The relation between the burst here described in which most or all the observed particles are electrons, and the large ion-chamber bursts can be determined only through further study.

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[3] Hoffman and Pforte, Phys. Zeits. **31**, 348 (1930). Stienke and Schindler, Naturwiss. **26**, 491 (1932).

The Disintegration of Aluminum by Swiftly Moving Protons

As in our experiments on lithium and boron,[1, 2, 3] we have bombarded aluminum with high velocity protons and have detected, with a Geiger point counter, radiations from the aluminum which penetrate about 8 cm of air. By comparing the absorption of the radiation in mica and aluminum with that in air we eliminated the possibility of an appreciable part of the observed radiation being soft x-rays and proved that particles were being observed. With the scintillation observations of Cockcroft and Walton[4] in mind, we presume the radiation consists of alpha-particles.

The disintegration particles have, as far as we can determine, a continuous distribution of ranges with a preponderance in the lower ranges. Using 1,200,000 volt-protons we observed about 1 particle given off per unit solid angle per 3.6 (10^8) protons having a range in excess of 4 cm while there were only a thirtieth as many with ranges greater than 7 cm. We have found also that the variation in the number of disintegration particles with energy of bombarding protons is the same for all ranges, and that the effective nuclear cross section for disintegration becomes sensibly constant for proton energies above 800,000 volts. In the case of lithium this constancy is reached in the neighborhood of 300,000 volts, while for boron the corresponding voltage is somewhat higher. Thus, for these elements at least it seems that the energy of bombarding protons requisite for nuclear penetration is approximately proportional to the atomic number.

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[1] Lawrence, Livingston and White, Phys. Rev. **42**, 151 (1932).

[2] Henderson, Phys. Rev. **43**, 98 (1933).

[3] White and Lawrence, Phys. Rev. **43**, 304 (1933).

[4] Cockcroft and Walton, Proc. Roy. Soc. **A40**, 19 (1932).