The Disintegration of Beryllium by Photons and Its Possible Bearing on the Mass of Be^9

Szilard and Chalmers[1] found that when beryllium was bombarded with the gamma-rays of radium in equilibrium with its decay products, neutrons were liberated, and could be detected by means of the radioactivity they excited in iodine. Meitner[2] showed that these neutrons excited radioactivity in I, Au and Ag, but not in Na, Si and Al. The former reactions involve the capture of a neutron, which, as Fermi[3] has shown, is most probable when the neutrons have little energy; while the latter three reactions involve the emission of an alpha-particle or proton, and probably have a higher probability when the bombarding neutrons have greater energies. Brasch and others,[4] working with x-rays, have obtained this disintegration at voltages between 1.5 and 2 mev.

In the present experiment, beryllium was bombarded with the x-rays from the tube in the Kellogg Radiation Laboratory. The tube is self-rectifying, and was supplied with 50 cycle a.c. at 0.9 mev peak. The electron current to the target was 2 m.a. The beryllium was located directly behind the tungsten target, in a bomb which was lowered inside the electrode. The ethyl iodide used as a detector for the neutrons was also in the bomb, just above the beryllium and in a Dewar vessel to prevent the heat generated at the target from reaching the ethyl iodide in the course of the irradiation, which lasted 40 minutes. The active iodine was separated from the ethyl iodide by the method of Szilard and Chalmers.[5] 200 g of beryllium and 375 cc of ethyl iodide were employed; the inside diameter of the bomb was 6.2 cm, and its overall length 25 cm. The intensity of radiation at 1 cm behind the target is calculated to be 2.5×10^4 r/min., on the basis of the measured intensity at 50 cm from the target and the known filtration in both cases.

The samples of iodine separated after irradiation were tested for activity with a quartz-fiber electroscope loaned by Professor C. C. Lauritsen. There was no increase over the background on the introduction of a sample. To check the sensitivity of the method, a test run was made with 370 mg of radium placed under the bomb in the position occupied by the target of the x-ray tube in the first experiment. The activation of the iodine in this case was easily measurable, initially more than doubling the cosmic-ray background. This poor yield in the case of the radium is to be attributed to the unfavorable geometrical conditions of necessity offered by the bomb; a much larger effect can be obtained by increasing the solid angles of irradiation.

Taking into consideration the relative intensities of the two sources of radiation, it may be said that an activation produced by the x-rays of one-one-thousandth the magnitude of that produced by the gamma-rays of radium would have been detected in this experiment. This may perhaps be reconciled with the statement of Gentner[6] that 0.9 mev radiation is most effective in the disintegration of beryllium, if one presumes that the efficiency of the process falls off sharply on the low-energy side of 0.9 mev, for the number of 0.9 mev quanta in the radiation produced in an x-ray tube excited with a.c. at 0.9 mev peak is very small.

If one is to suppose that beryllium is disintegrated into two alpha-particles and a neutron by a high energy photon, and that the enormously reduced yield just below a million volts found in this experiment indicates the existence of a genuine threshold for the phenomenon, then it seems possible that the mass of Be^9 is too high. If we fix the threshold at 0.9 mev and take the mass of the neutron as 1.0080, then, on our assumptions, the mass of Be^9 must be 9.0114, a result which explains the anomaly of the stability of Be^9, as well as Bonner and Brubaker's[7] results on the energy of the neutrons from Be bombarded with deutons. Miss Meitner's[8] result that radioactive B^9 is formed in the reaction

$$_3Li^6 + {_2He^4} \rightarrow {_5B^9} + {_0n^1} \rightarrow {_4Be^9} + {_1e^+} + {_0n^1}$$

is additional evidence for this mass of Be^9, as Professor Lauritsen has pointed out to us.

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Evidence for a Positron-Negatron Component of the Primary Cosmic Radiation

Recent studies of the cosmic-ray shower intensities and their dependence on latitude, elevation and direction have brought forth some new results which seem to throw important light on the nature of the primary radiation. For measuring the intensity of showers, three coincidence counters were mounted with their axes horizontal and at the vertices of an upright equilateral triangle. Immediately above the upper counter was a lead plate 1.2 cm thick and slightly larger than the cross-sectional area of a single counter. The counts thus recorded were corrected for accidental coincidences and the result was taken as a measure of the intensity of the shower producing radiation (I_s). The same three counters were also mounted in vertical line and the counting rate in this position, corrected for accidental coincidences and sidewise showers, was taken as a measure of the total radiation incident from the

TABLE I. *Shower and vertical intensities.*

Station	Geomagnetic latitude	Elevation (meters)	I_s Shower intensity (counts per min.)	$I_\perp$ Vertical intensity (counts per min.)	$I_s/I_\perp$
Swarthmore	50°	100	2.2	12.9	0.17
Vera Cruz	28°	20	2.3	11.9	0.19
Mt. Evans	50°	4300	15.0	36.8	0.41
Nevado de Toluca	29°	4300	11.4	28.2	0.40
Copilco	29°	2280	7.4	22.8	0.32
Parral	36°	1730	4.6	17.5	0.26

vertical direction ($I_\perp$). The ratio ($I_s/I_\perp$) of shower intensities to vertical intensities was thus independent of changes of sensitivity which might be feared in moving the apparatus from one station to another. The corrected rates and their ratios for six stations are given in Table I and they display the following interesting features. In the first place, the ratio ($I_s/I_\perp$) increases with elevation, showing that the showers are relatively more intense at high elevations. This agrees with the results of similar measurements[1] made in August, 1933, in Peru, and with the results of Rossi[2] in Erythrea. The second feature of interest is the fact that at high elevations $I_s/I_\perp$ does not vary with latitude, and at sea level it decreases with increasing latitude. Thus the high elevation showers are due to primaries which are affected by latitude to about the same extent as the total vertical radiation, whereas the sea-level showers are due to rays of such energies that they are not affected by these changes in latitude to as great an extent as $I_\perp$.

A second series of experiments was carried out on Nevado de Toluca in Mexico in which a similar shower measuring arrangement was used for investigating the azimuthal symmetry of the shower producing radiation. To obtain better directional resolution the counters, in this instance, were placed at the vertices of an isosceles triangle, 23 cm in altitude and 9 cm base, with the same plate of lead over the upper counter and parallel to the base. In two runs this arrangement was inclined from the vertical 35° and 49°, respectively, and at regular intervals it was rotated about a vertical axis between the east and west azimuths. The results of these experiments are contained in Table II and they show that the shower producing

TABLE II. *Shower asymmetry on Nevado de Toluca. Elevation 4300 m, geo. mag. lat. 29°.*

Zenith angle	$(I_w+I_e)/2$ (counts per min.)	$2(I_w-I_e)/(I_w+I_e)$
35°	3.70	$0.012\pm.011$
49°	2.50	$0.018\pm.010$
35° (without lead)	1.08	

radiation is almost completely symmetric about the meridian plane. For comparison it is noted that the total western radiation, measured with three counters in line, at the same station was 10 and 13 percent more intense than the eastern radiation at these same angles. It seems impossible to account for this symmetry by the failure of the apparatus to resolve directional effects since the shower intensities did show marked variation with the zenith angle. Also it was found by removing the lead that more than two-thirds of the counts recorded were due to showers produced in the lead and this presented a much larger area towards the azimuth in which it was pointing than to the opposite azimuth. Since shower intensities vary with latitude, they must be due to primary charged rays, and the azimuthal symmetry must mean that these are about equally divided between positives and negatives.

This suggests that the primary shower producing component consists of positrons and negatrons, while the radiation which produces the asymmetry measured by counters in line is due to more penetrating corpuscles, presumably protons. This is somewhat similar to the hypothesis proposed on other grounds by Compton and Bethe,[3] and is in line with the findings of Anderson, Blackett and others that the intermediate shower producing radiation probably consists of photons, for it is perhaps less difficult to account for the production of these photons by primary electrons than by protons. It is possible that some of the events which are recorded by the shower measuring arrangement can be produced by protons, and if so, these would represent a larger fraction of the total at sea level. This would seem to be the explanation of the asymmetry in showers found at sea level on the equator,[1] and of the slight asymmetry shown by the present measurements at high elevations in Mexico.

On the basis of the openings of the cones for rays of various energies, given in 1933 by Vallarta, the positive component alone seemed sufficient to account for the whole of the latitude effect.[1] The recent calculations of Lemaitre, Vallarta and Bouckaert,[4] on the other hand, give values for the openings of the cones such that the asymmetries and latitude effects can be made to accord with one another only by assuming the existence of a negative component as well. Estimates of the magnitude of this component will be made in a later publication.

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