Production of Neutrons by High Speed Deutons

In a recent letter to the *Physical Review*[1] we described briefly an apparatus for the acceleration of positive ions and the production of neutrons by bombarding beryllium with helium ions of from 600,000 to 975,000 electron-volts energy. Since then we have bombarded targets of lithium chloride and beryllium with deutons of energies up to 900,000 electron-volts, and have obtained in both cases yields of neutrons several hundred times as great as the yield previously obtained by bombarding beryllium with helium ions.

The same apparatus was used for accelerating the ions and for detecting the neutrons as was described in the previous letter. A sensitive electroscope, the inside walls of which were coated with paraffin, was entirely enclosed in a lead cylinder of 5 cm wall thickness to shield it from x-rays. The neutrons supposedly penetrate the 5 cm of lead and eject recoil hydrogen particles from the paraffin on the inner walls of the electroscope. It is the ionization due to these recoil particles that gives a measure of the intensity of neutrons passing through the chamber. The lead cylinder with the electroscope inside was placed in such a position that the center of the electroscope was 13 cm from the center of the target, and in a direction from it perpendicular to the incident ion beam.

In making the measurements of neutrons produced by deuton bombardment, it was necessary to make several comparison measurements in order to establish the fact that in each case the observed effect was due to neutrons rather than to γ-rays, and that the disintegration was produced by the deutons rather than protons. The hydrogen used to produce the deutons contained only 5 percent of the heavy isotope, so even in the so-called deuton measurements, the greater part of the ions was protons. Each target bombarded with deutons was later bombarded with 100 percent protons for comparison. No effect was observed with protons, except a slight one in the case of lithium, which is discussed below, and it was therefore concluded that the large effects were produced by deutons. Measurements were also made with deutons, with the paraffin removed from the electroscope. With both lithium and beryllium the rate of discharge without paraffin was less than half that with paraffin, indicating that the greater part of the ionization observed was due to recoil particles ejected from the paraffin by neutrons, rather than to γ-rays. The sensitivity of the electroscope to 600,000 volt x-rays filtered through 5 cm of lead was measured and found to be slightly greater without paraffin than with paraffin.

Curves of the efficiency of production of neutrons from lithium chloride and from beryllium as a function of voltage are shown in Fig. 1. The total ion current during all the measurements was 10 microamperes. The background, indicated by a straight line, is the rate of discharge of the electroscope due to x-rays plus its natural leak, and is the same in all cases in which no neutrons or γ-rays are produced. It has been determined by bombarding a brass target with helium ions, a beryllium target with protons, and a brass target with protons.

The lithium chloride target, bombarded with 10 microamperes of protons at 800,000 volts gave a small effect, about twice the background, which was decreased to less than half that when the paraffin was removed from the electroscope, indicating that the radiation was neutrons. It is possible that this is a double process in which the α-particles produced by proton bombardment in turn disintegrate lithium with the production of neutrons. It has

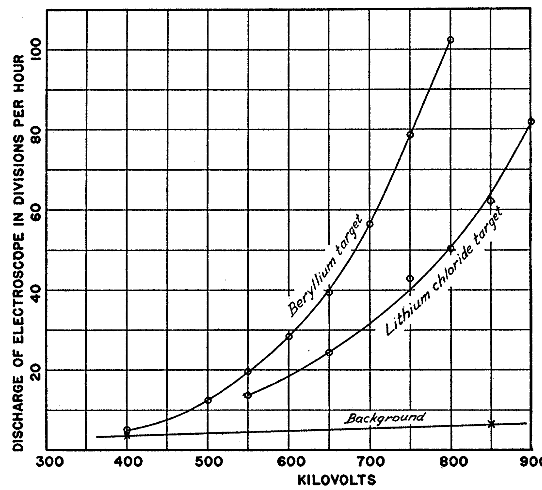

FIG. 1.

already been shown by Curie and Joliot[2] that α-particles of long range are capable of producing neutrons from lithium, and the effect here observed seems to be of the right order of magnitude to be accounted for in that way. However, the effect is to be investigated further.

The simplest hypotheses as to the nature of the two disintegrations with deutons are:

$$Be^9+H^2\rightarrow B^{10}+n^1,$$

$$Li^7+H^2\rightarrow 2He^4+n^1.$$

Assuming tentatively that the mass of the neutron is 1.0065, and taking as values of the other atomic masses referred to O^{16}

Li^7 7.0146	B^{10} 10.0137	H^2 2.0136
Be^9 9.0155	He^4 4.0022	

we find that in the case of the disintegration of beryllium the neutron comes off with a kinetic energy of about 9×10^6 electron-volts. In the case of lithium, the kinetic energy of the neutron plus that of the two α-particles comes out to be about 16×10^6 electron-volts. It is probable that these calculations will be greatly modified by subsequent experimental data, but they serve as a rough approximation

[1] Crane, Lauritsen and Soltan, Phys. Rev. **44**, 514 (1933).
[2] Curie and Joliot, J. de Physique **4**, 278 (1933).

to show that the neutrons produced by this method have a rather high kinetic energy.

It is of interest to make a comparison of the intensity of neutrons produced by bombarding beryllium or lithium with deutons with that obtained by bombarding beryllium with α-particles from a strong polonium source. One division in our electroscope corresponds to about 70 recoil hydrogen particles. At our maximum deuton current (30 microamperes) and at 900,000 volts, about 1000 recoil particles per minute would be obtained, which is of the order of one hundred times the intensity obtained by means of the strongest polonium α-particle sources now in use. It is therefore possible, by the use of deutons, to obtain an efficiency in the artificial production of neutrons which is comparable with the efficiency of production of α-particles by proton bombardment.

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