LETTERS TO THE EDITOR

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Communications should not in general exceed 600 words in length.

$(d, 2n)$ Reaction in Copper

Recently a stack of one-mil copper foils was bombarded with 16-Mev deuterons from the 60-inch Berkeley cyclotron. The activity of each foil was followed with an electrometer. Fig. 1 shows the results obtained.

A strong activity apparently assignable to the reaction $Cu^{63}(d, 2n)Zn^{63}$ (half-life 38 minutes)[1] was observed. Further study verified this assignment and revealed several properties of the reaction.

Curve 1 (Fig. 1) gives the relative cross section (in arbitrary units) for the formation of Zn^{63} at various bombarding energies. (Zn^{63} activity at highest point plotted in Fig. 1 is of the order of a half-millicurie.) The energy plotted is that at the center of the respective foils ($\sim$10 cm air equivalent each). The maximum energy of the cyclotron beam was fixed as 16 Mev by the frequency and geometry of the cyclotron. The energy was calculated for each foil from the residual range, measured visually with the aid of a ZnS screen, and the formula of Livingston and Bethe. The inhomogeneity of the beam, and the fact that the maximum energy of the beam measured visually is about 7 percent less than that calculated by the frequency and geometry makes the energy scale somewhat uncertain.

The threshold of the reaction $Cu^{63}(p, n)Zn^{63}$ is variously reported as 3.6 Mev[2] and 4.1 Mev.[3] The threshold of the $Cu^{63}(d, 2n)Zn^{63}$ reaction should be higher than this value by an amount equal to the binding energy of the deuteron (2.2 Mev), or approximately 6 Mev. Qualitatively one would expect the yield curve to be flat near the threshold because (1) the Oppenheimer-Phillips process competes to give active Cu^{64}, (2) the Coulomb barrier is $\sim$8 Mev, and (3) on Bohr's compound nucleus model of disintegration, the probability near the threshold for the emission of two neutrons is very much smaller than that for the emission of a proton or single neutron. The ratio $\sigma(d, 2n)/\{\sigma(d, n)+\sigma(d, 2n)\}$ can be calculated from the theory of Weisskopf[4] and indicates that the $(d, 2n)$ reaction should be observable first at about 7 Mev. Activated contaminants in the copper limited the measurements of Zn^{63} activity near the threshold. Even with chemical separation of the zinc, activity could be established definitely only as low as 7.5 Mev. These latter data were obtained by bombarding 0.1-mil copper foils with 8.5-Mev deuterons produced by the 37-inch Berkeley cyclotron (the beam energy being varied by aluminum absorbers). The use of the smaller cyclotron increased considerably the accuracy of measurements of the beam energy near the threshold.

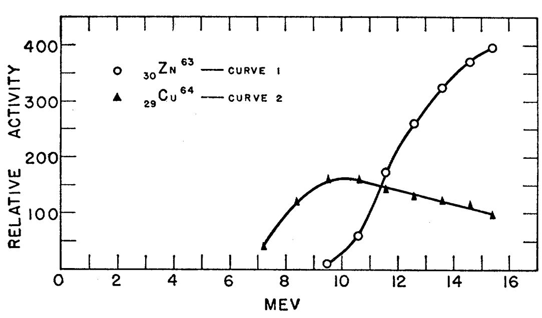

FIG. 1. Relative cross sections of Zn^{63} and Cu^{64}.

Absorption curves in aluminum indicated that the energy of the electrons was in agreement with previously reported values.

Curve 2 (Fig. 1) gives the relative cross section on the same scale for the production of Cu^{64} (half-life 12.8 hours) obtained by following the activities in the same stack of foils. The maximum observed can be explained qualitatively as follows. Cu^{64} can be formed by the Oppenheimer-Phillips process or by the (d, p) process with the deuteron entering the nucleus. The excited Zn^{65*} may disintegrate by emission of (p), (n), $(2n)$, $(n$ and $p)$, etc., the last two becoming more probable as the excitation energy increases. The Oppenheimer-Phillips process will gradually decrease above the barrier ($\sim$8 Mev) and competition between the above processes will become more important.

Clearly these processes can account for the same effect (falling off of Cu^{64} yield near 9 Mev) observed by Krishnan and Banks[5] and attributed by them to competition of $Cu^{63}(d, 2n$ and $p)Cu^{62}$. The latter reaction has been shown to be energetically impossible at 9 Mev by Goldhaber.[6]

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