of proton and deuteron bombardments of enriched Se^{74}. In the present experiments, the reaction producing this isotope would be $Cu^{65}(C, 2n)Br^{75}$. The 36-minute activity has not been reported previously.

The 16-hour positron emitter Br^{76} has not been observed in any carbon ion bombardments of copper. From the gross activity curves, which decay to background without tailing out into a longer component, a lower limit of ~30 can be set on the ratio of the $Cu^{65}(C, 2n)Br^{75}$ to the $Cu^{65}(C, n)Br^{76}$ reaction.

In an attempt to fix the isotopic assignment of the 36 minute bromine relative to 95 minute Br^{75}, carbon ion bombardments of isotopically enriched CuO targets[4] were made. The CuO samples carried the following analyses:

CuO I: Cu^{63}, 99.7±0.3%; Cu^{65}, 0.3%.
CuO II: Cu^{63}, 1.84±0.02%; Cu^{65}, 98.16±0.02%.

Br^{75} can be produced by carbon ions only from Cu^{65}, since a $Cu^{63}(C, \gamma)Br^{75}$ reaction would not be likely. Thus, from CuO I, any Br^{75} which is produced should have come only from the ~0.3 percent Cu^{65} remaining in that sample. One would then expect the ratio Br^{75} (from CuO II)/Br^{75} (from CuO I) to be ~300. Actually observed in two bombardments were ratios of 50 and 100, which, considering the experimental uncertainties in carbon ion beam current and chemical yields, are not inconsistent with the isotopic enrichment reported.

The cross sections for the $Cu^{65}(C, 2n)Br^{75}$ reaction and the $Cu^{65}(C, xn)$ 36 min $Br^{<76}$ reaction were roughly equal, indicating that the latter activity may be due to the $Cu^{65}(C, 3n)Br^{74}$ or $Cu^{65}(C, 4n)Br^{73}$ reaction. However, there was no appearance of the 7.1-hour Se^{73} in any of the bromine decay curves, so it is fairly certain that the 36-minute bromine does not decay through that state. In addition, the following evidence points to its assignment to Br^{74}: in spite of over a fiftyfold enrichment of Cu^{63} in CuO I as compared with CuO II, the ratio of 36 minute/95 minute activities was only slightly enhanced in CuO I, and the absolute yield of the 36-minute activity was lower by a factor of about 50 in CuO I than in CuO II, indicating that the 36-minute activity has been made in Cu^{63} by a reaction with a very low cross section, and hence may be assigned tentatively to Br^{74}, by the $Cu^{63}(C, n)Br^{74}$ reaction.

In carbon-ion bombardments of $Cu^{63}O$, but not in those of $Cu^{65}O$, a 4±1 minute bromine activity has also been observed but no further details are presently known about this activity.

I am greatly indebted to Drs. I. Perlman and M. I. Kalkstein for their helpful comments, and to G. B. Rossi and the crew of the 60-inch cyclotron for their help in making these bombardments.

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[*] This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] Ghiorso, Thompson, Street, and Seaborg, Phys. Rev. **81**, 154 (1951).

[2] J. M. Hollander, University of California Radiation Laboratory Report UCRL-1395, June, 1951 (unpublished).

[3] Woodward, McCown, and Pool, Phys. Rev. **74**, 870 (1948).

[4] These enriched samples were kindly loaned by the Stable Isotopes Division of the Oak Ridge National Laboratory.

High-Energy (γ,d) Reactions*

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(Received August 27, 1953)

Using a technique which electronically separates deuterons from protons,[1] we have measured $(\gamma,d):(\gamma,p)$ ratios at 90° in the laboratory system using C, Cu, and Pb targets. Figure 1 shows the experimental arrangement. The γ-ray beam from the 310-Mev Cornell synchrotron strikes a target and the product particles are analyzed in a two-crystal telescope. The energy of the particle is measured in the second crystal, 5.5 g/cm^2 of NaI, and dE/dx of the particle is measured in the first crystal of 0.35 g/cm^2 of NaI. The pulses from the two crystals are multiplied electronically; the product pulse EdE/dx being approximately proportional to $M^{0.8}Z^2E^{0.2}$. The mass dependence of the product makes possible the identification of protons and deuterons, and since the product varies slowly with energy, a large range of energies can be examined at the same time.[2]

In practice, an energy interval is set by upper and lower biases on the second crystal, for example, 27–37 Mev for most of this experiment. The experiment is now sensitive to two groups of particles. Particles of group 1 have energies between 27 and 37 Mev after going through the first crystal and stop in the second crystal. Group 2 with energies between about 70 and 90 Mev for protons and 115 and 145 Mev for deuterons go completely through the second crystal and lose 27–37 Mev in it. Since $dE/dx \sim M^{0.8}/E^{0.8}$, group 2 particles lose much less energy in the first crystal than do the particles of group 1. We are therefore able to discriminate against the second group by setting a lower limit to the pulses accepted from the first crystal. This technique provides a convenient method of obtaining a variable energy interval and at the same time eliminates the need for a separate anti-coincidence crystal.

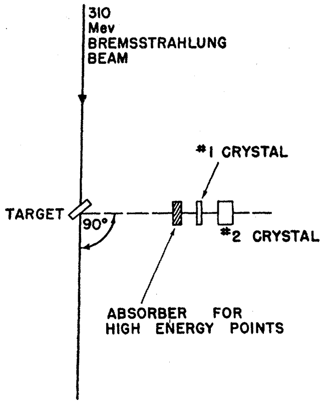

FIG. 1. Arrangement of apparatus.

The multiplication is accomplished essentially by charging a condenser at a rate proportional to the pulse height in one crystal and for a time proportional to the pulse height in the second crystal. The accumulated charge is then proportional to the product of the pulse heights. Figure 2 shows the distribution of

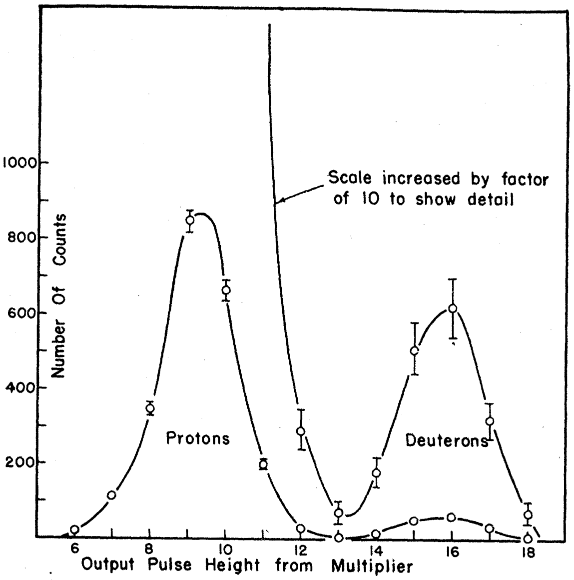

FIG. 2. Illustration of the resolution of the deuteron detector. The data above were obtained using a Cu target with the system sensitive to 43–51 Mev deuterons.

output pulses from the multiplier obtained for the case of 47-Mev deuterons from Cu, the first peak being protons, the second, deuterons.

Particles of energy greater than 45 Mev were measured by placing absorbers in front of the two-crystal telescope. With absorber in place, the protons detected are of slightly different energy than the deuterons. To obtain the ratio for protons and deuterons of the same energy, the known[3,4] proton spectrum was used.

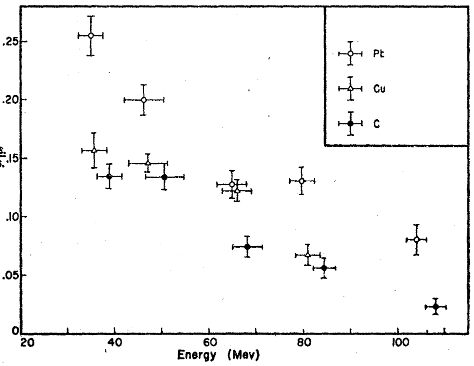

FIG. 3. The ratio of deuterons to protons produced by 310-Mev *bremsstrahlung* at 90° in the laboratory. The abscissa represents the energy of the product particles. The statistical errors are shown.

Figure 3 shows the ratio of the number of deuterons to protons per unit energy interval at various energies at 90° in the laboratory system. The *A* and *Z* dependence and the energy dependence of these ratios is suggestive of a (γ,n) or (γ,p) reaction followed by a pickup process.

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* Work supported by the U. S. Office of Naval Research.

[1] Wolfe, DeWire, and Silverman, 1953 Washington meeting of the American Physical Society [Phys. Rev. 91, 22 (1953)]. We are preparing a more detailed description of this apparatus for publication in *The Review of Scientific Instruments.*

[2] It should be pointed out that if the product $E^{0.8}dE/dx$ were used, there would be no energy dependence.

[3] C. Levinthal and A. Silverman, Phys. Rev. 82, 822 (1951).

[4] J. C. Keck, Phys. Rev. 85, 410 (1952).

Elastic Photoproduction of π^0's from Deuterium*

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(Received August 27, 1953)

We have investigated the reaction $\gamma+D\rightarrow\pi^0+D$ for γ-ray energies between 250 Mev–300 Mev and π^0 mesons emitted at 90°–120° in the laboratory. Figure 1 shows the experimental arrangement. The deuteron detector is described in the previous letter.[1] The γ-ray counter detects one of the decay γ rays from the π^0. An event is recorded by a deuteron-γ-ray coincidence. Measurement of the energy and angle of the recoil deuteron determines the energy of the γ ray and the energy and angle of the π^0.

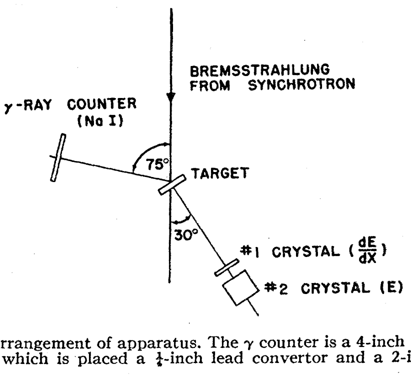

FIG. 1. Arrangement of apparatus. The γ counter is a 4-inch NaI crystal in front of which is placed a ¼-inch lead convertor and a 2-inch carbon absorber.

The experiment is performed by taking a D_2O-H_2O difference. The distribution of pulse heights from the multiplier[1] for both D_2O and H_2O are shown in Fig. 2. With the D_2O target, the distribution shows two peaks corresponding to protons and deuterons, whereas the results for H_2O show only a proton component.

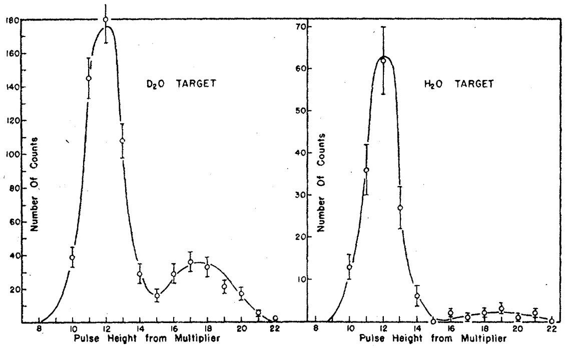

FIG. 2. Comparison of the multiplied pulse distribution for D_2O and H_2O targets, showing the large number of deuterons from D_2O. The D_2O run was for an integrated beam intensity of $7.63\times10^{11}Q$ while the H_2O run was for $3.72\times10^{11}Q$.

Several auxiliary experiments were done to check that the observed deuterons were recoils from the reaction $\gamma+D\rightarrow\pi^0+D$. (a) A 0.040-in. Cu absorber was placed in front of the deuteron detector which was just sufficient to make the detector insensitive to the highest-energy deuteron expected from the reaction; (b) the deuteron detector was moved to 70° where no recoils from the above reaction can occur; (c) the maximum energy of the synchrotron was reduced to 250 Mev so that no deuteron could have sufficient energy to be recorded. In each of these experiments, the deuteron peak disappeared and there was no detectable D_2O-H_2O difference.

This reaction is of special interest because the cross section depends rather sensitively, through interference effects, on the relative sign of the neutron and proton π^0 coupling constants, g_p and g_n. There have been several calculations of this process using the impulse approximation.[2] All of these calculations arrive at approximately the same result and may be roughly summarized as follows: Where the impulse approximation is good, the cross section for the elastic production can be written as

$$\sigma_{\text{elastic}}=|A_n+A_p|^2|I(\mathbf{k}/2)|^2. \tag{1}$$

A_n is the amplitude for π^0 production from the neutron and A_p is the same for the proton. I is an integral that depends only on the wave function of the ground state deuteron and is written as

$$I(\mathbf{k}/2)=\int|\psi_D(\mathbf{R})|^2e^{i\mathbf{k}\cdot\mathbf{R}/2}d\mathbf{R}.$$

In the same approximation, the total cross section (elastic and inelastic) can be written as

$$\sigma_{\text{total}}=A_p^2+A_n^2+2\,\mathrm{Re}(A_p^*A_n)I(\mathbf{k}/2). \tag{2}$$

For $I(\mathbf{k}/2)\ll1$,[3] the interference term can be neglected and the total cross is just the sum of the two free cross sections:

$$\sigma_{\text{total}}=A_p^2+A_n^2.$$

Measurements at this laboratory[4] and recently confirmed at Berkeley[5] show that

$$\sigma_{\text{total}}\ (\text{deuterium})/\sigma\ (\text{hydrogen})\approx2.$$

This implies that $A_p\approx A_n$.