A collimated beam of 14.1-Mev neutrons from the $H^3(d,n)He^4$ reaction was incident upon a 4-mil normal zirconium target at the center of a nuclear-plate camera.[1]

Ilford E-1 plates were placed around the periphery of the camera floor, with their long axes coinciding with radii extending from the center of the base of the camera. Two runs were made, one with the target in position and the other a background run without the target.

Equivalent areas on run and corresponding background plates were analyzed at eight camera positions such that the angles made by the reaction particles with the direction of the incident neutron beam extended from 17.5° to 128°. Measurements were made of all tracks longer than 10 microns entering the surface of the emulsion in directions consistent with target-detector geometry. The tracks were further identified, from grain density, as proton or α-particle tracks. Thus data for the (n,p) cross section were obtained at the same time as those for the (n,α) cross section.

The value obtained for the (n,α) cross section integrated from 17.5° to 128° is 10 ± 10 mb for reaction α particles of energy greater than 3 Mev. Since in these calculations it is assumed that all the stable isotopes of normal zirconium contribute to the observed reaction particles, the value given is one-half the upper limit for Zr^{90}.

A preliminary value for the (n,p) cross section obtained from this experiment is 180 ± 70 mb, which is in fair agreement with that given by Paul and Clarke.[2] The energies of essentially all the observed reaction protons are below 6 Mev.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Allred, Armstrong, and Rosen, Phys. Rev. **91**, 90 (1953).
[2] E. B. Paul and R. L. Clarke, Can. J. Phys. **31**, 267 (1953).

14-Mev (n,α) Cross Section in Zirconium. III*

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A DIRECT measurement of the yield of alpha particles produced by bombarding normal zirconium with 14.1-Mev neutrons has confirmed the smallness of the Zr^{90} and Zr^{94} (n,α)-reaction cross sections observed by the activation measurements of Brolley *et al.* reported in the first of the preceding letters.

A one-mil foil of zirconium metal was bombarded with monoenergetic neutrons from the $H^3(d,n)He^4$ reaction, and the alpha particles were detected by means of a counter telescope, consisting of two proportional counters and a NaI(Tl) scintillator, described in detail elsewhere.[1] The counters were biased to a lower limit of ionization energy loss so that alpha particles of energies ≤ 18 Mev were detected, while protons and deuterons of energies ≥ 0.8 and 1.6 Mev were excluded.

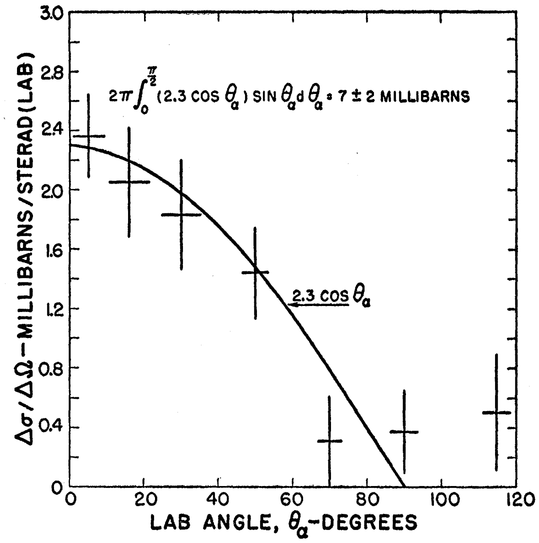

FIG. 1. Differential cross section for the yield of alpha particles of energies greater than six Mev from normal zirconium bombarded by 14.1-Mev neutrons.

At each telescope angle the scintillator pulse-height spectrum was observed between alpha-particle energies of 6 and 18 Mev. Background was measured by exposing a platinum blank to the telescope. The energy spectrum at zero and 15 degrees was peaked at its upper limit of 17 Mev and decreased to zero at about 10 Mev. Between 10 and six Mev, no alpha particles were observed. At larger angles, up to 115 degrees, yields were too low for significant spectrum determinations.

The measured differential cross section of Fig. 1 has been fitted somewhat arbitrarily to a cosine function whose integral over the forward hemisphere is 7 ± 2 millibarns. This is of course a weighted average of the (n,α) cross sections of the five stable isotopes of zirconium for alpha particles of energies greater than six Mev. However, the upper-limit value of the cross section for alpha particles of energies as low as three Mev found by Armstrong and Brolley[2] indicates that there is no significant contribution to the yield in the energy region from three to six Mev. The degree of agreement of both of these values with those of Brolley *et al.* for the Zr^{90} and Zr^{94} cross sections precludes a large yield of alpha particles below both the 3- and 6-Mev energy limits such as would be necessary to account for the large $Zr^{90}(n,\alpha)$ cross section of 194 millibarns found by Paul and Clarke. The fact that our value is somewhat larger than that of Brolley *et al.* is probably due to the fact that transitions to the ground state of Sr^{87}, as well as to the isomeric state, contributed to our yield. In addition, there are contributions from the other three isotopes of normal zirconium.

A separate search gave no indication, within statistics, of a yield of protons of energies greater than about five Mev, in agreement with the results of Armstrong and Brolley.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] F. L. Ribe and J. D. Seagrave, Phys. Rev. 94, 934 (1954).
[2] A. H. Armstrong and J. E. Brolley, Jr., preceding Letter [Phys. Rev. 99, 330 (1955)].

Resonances in the Elastic Scattering of Protons*

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THE purpose of this note is to report the existence of nuclear resonances of an unusual type in carbon and oxygen. These resonances were found during a search for anomalies in the elastic scattering of protons using the 32-Mev linear accelerator of this laboratory. The apparatus was that used by Eisberg and Igo.[1] The protons scattered elastically from a thin target (about 20 mg/cm^2) were detected by a plastic scintillator and counted after pulse-height analysis. The experimental procedure consisted in fixing the angle of scattering near the first minimum of the diffraction pattern and plotting the counting rate against the energy of the incident proton beam, which was altered by absorption in polystyrene. Smooth variations of the counting rate with the proton energy were found with most targets. These variations correspond to the slow displacement of the maxima and minima of the diffraction pattern. In carbon and in oxygen, however, the smooth curve is interrupted by a sharp peak which rises about 20 percent above the mean counting rate in its immediate vicinity. In carbon, the energy of the peak is 22.5±0.3 Mev; the width at half-maximum is about 1.5 Mev. The results obtained with a polystyrene foil of about 15 mg/cm^2 are shown in Fig. 1. The effect on the diffraction pattern is shown in Fig. 2; the minimum is filled in near the peak of the resonance and regains its normal shape within 1 Mev on either side of it. The oxygen resonance was first found in a comparison of the elastic scattering of silicon and silica. The data shown in Fig. 3 were obtained with a gaseous target. The peak is at 18.6±0.3 Mev, and the width is about 1.3 Mev. The oxygen resonance is well marked for angles near the minimum of the diffraction pattern but is too small to be detected when the counting rate, at other angles, rises much above this minimum value. In carbon and oxygen no other resonance was found in a proton energy range of 14 to 31.5 Mev. A search for similar resonance in B, N, F, Al, Si, S, Ca, Fe, and Cu, over the same energy range, gave no result. This does

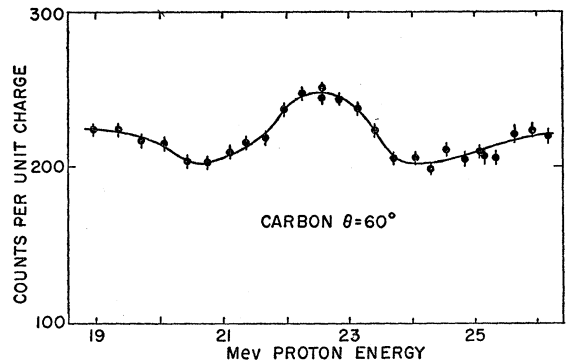

FIG. 1. Resonance in the elastic scattering of protons from carbon at 60°.

not exclude the existence of resonances in these nuclei, for the method is effective only for resonances which are neither too narrow (less than 200 kev) nor too broad (more than 3 Mev). The measured widths are close to the natural widths for they are large compared with both the proton energy loss in the targets—400 kev and 100 kev, for carbon and oxygen, respectively—and the spread in energy of the proton beam—about 100 kev.[2]

It is unlikely that the resonances found in carbon and oxygen are size resonances, because they are much sharper than would be expected theoretically and because no resonance was found in nitrogen, which lies intermediate in atomic weight. Now in carbon there is no anomaly in the cross section[3] of the $C^{12}(p,pn)C^{11}$ reaction near 23 Mev. The observed effect, therefore, demonstrates, in a narrow energy range, an increase in the probability of elastic re-emission of the proton. This is a characteristic to be expected of a single-particle state. It is unlikely, however, that the

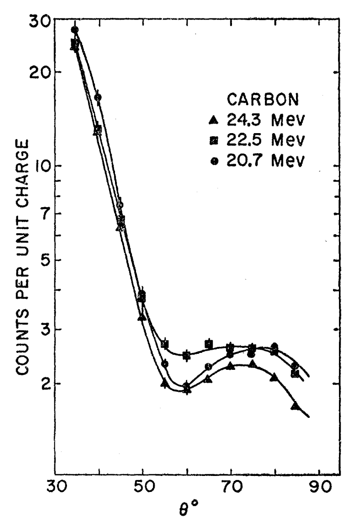

FIG. 2. Angular distribution of protons scattered elastically from carbon, at the peak of the resonance (squares), and above (triangles) and below it (circles).