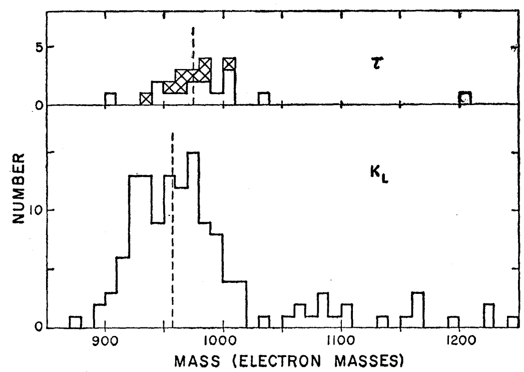

FIG. 2. Mass distributions: Upper histogram represents τ mesons. Crossed squares refer to τ's found nonsystematically. Lower histogram is made up of particles decaying into a single lightly ionizing secondary.

comparison of the measured τ meson mass of (974 ± 6) m_e with the accepted value[3] of 966 m_e indicates a possible systematic error.

This work was done with the encouragement and guidance of Professor Chaim Richman. Most of the scanning was performed by Mrs. Beverly Baldridge, Miss Irene d'Arche, Mrs. Marilynn Harbert, Mrs. Edith Goodwin, and Miss Kathryn Palmer.

It is with pleasure that we acknowledge the help and advice in nuclear emulsion techniques given us by Professor Powell's group at Bristol. The assistance of the Bevatron crew, under the direction of Dr. Edward J. Lofgren, and their skillful operation of the machine are greatly appreciated.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
† National Science Foundation Predoctoral Fellow.
[1] Kerth, Stork, Birge, Haddock, and Whitehead, Bull. Am. Phys. Soc., Vol. 30, No. 3, 41 (1955).
[2] Courant, Livingston, and Snyder, Phys. Rev. **88**, 1190 (1952).
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14-Mev (n,α) Cross Sections in Zirconium. I*

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IN a survey of neutron-induced reactions, Paul and Clarke[1] quote a value of 194 ± 107 mb as a lower limit for the 14.5-Mev (n,α) cross section in Zr^{90}, and 63 ± 25 mb for this process in Rh^{103}. Brolley and Dickinson[2] conducted a direct search for the alpha particles from these elements using neutrons of about 14.3 Mev in an attempt to observe any variation in barrier height with angle. In this work the valuable help of the nuclear plate and Cockcroft-Walton groups is gratefully recognized. Their study indicated considerably smaller cross sections than reported by Paul and Clarke. The problem has been re-examined using several different methods by A. Armstrong and J. E. Brolley, Jr., F. L. Ribe and R. W. Davis, and the present authors. In the following Letters the results and the compatibility of the several experiments are discussed by A. Armstrong and J. E. Brolley, Jr., and F. L. Ribe and R. W. Davis.

We have bombarded various samples of normal zirconium metal with neutrons of average energy 14.1 and 14.9 Mev produced by the Cockcroft-Walton machine. Strontium was chemically separated from the zirconium and counted with a Na(Tl)I crystal whose sensitivity was known for the γ radiations from Sr^{87m} and Sr^{91}. Table I presents the results.

The standard deviations indicated are essentially those of counting. The Zr^{90} cross sections apply to the production of the isomer only. The diminution of these cross sections with increasing neutron energy may possibly be associated with competition from the $(n,2n)$ process. These cross-section values fall markedly below the trend of $\sigma_{obs}/\sigma_{calc}$ cited by Paul and Clarke. Though all nuclei in these processes have magic numbers or near magic numbers of neutrons (50), the (n,α) cross sections of neighboring nuclei are not sufficiently well established to discern a correlation with neutron number. We are indebted to R. W. Davis for invaluable help in the irradiations.

TABLE I. (n,a) cross section in mb. Neutron energy, E_n, in Mev.

E_n	14.1	14.9
Zr^{90}	3.1 ± 0.2	3.0 ± 0.2
Zr^{94}	4.9 ± 0.6	3.9 ± 0.5

* Research performed under the auspices of the U. S. Atomic Energy Commission.
[1] E. B. Paul and R. L. Clarke, Can. J. Phys. **31**, 267 (1953).
[2] J. E. Brolley and W. C. Dickinson (unpublished).

14-Mev (n,α) and (n,p) Cross Sections in Zirconium. II*

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FURTHER confirmation of a low value for the (n,α) cross section for zirconium bombarded by 14.1-Mev neutrons has been obtained in still another experiment, in which nuclear plates were used as detectors of the reaction products.

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.

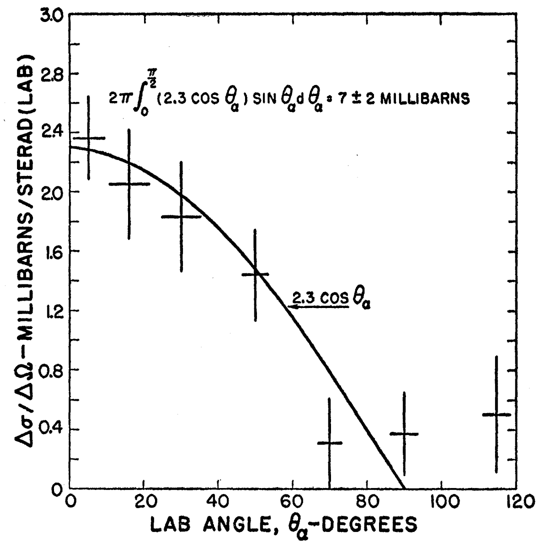

FIG. 1. Differential cross section for the yield of alpha particles of energies greater than six Mev from normal zirconium bombarded by 14.1-Mev neutrons.

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.