excluded. The possibility that a relatively sharp group has been smeared out experimentally can be discarded, because of the small thickness of the target and the high resolution of the spectrometer. The reactions $Li^6(d,\alpha)He^4$ and $Li^6(d,He^3)He^5$ do not yield α particles which could contribute to the spectrum in the energy range observed. Delayed α particles from the decay of Be^8 levels formed via $Li^7(d,p)Li^8-\beta^-\rightarrow Be^8$ would have been easily identified, but none were observed.

The shape of the alpha spectrum at $\theta=90°$ has been studied at several other deuteron energies up to $E_d=2.2$ Mev. No group, except the one belonging to the He^5 ground state was found; i.e., the spectra had essentially the shape given in Fig. 1.

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Measurements of (n,α) Cross Sections at 14 Mev

H. G. Blosser, C. D. Goodman, and T. H. Handley
Oak Ridge National Laboratory, Oak Ridge, Tennessee*
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Results of activation measurements of the (n,α) cross section of nine isotopes ranging in mass number from 59 to 133 are reported. The measurements were made at a neutron energy of 14±0.5 Mev using neutrons from the $D(t,n)He^4$ reaction. The cross sections show a markedly different dependence on mass number from that reported in a previous survey.

INTRODUCTION

In a previous paper[1] (hereinafter referred to as BGHR), results of activation measurements of the (n,α) cross sections of the isotopes Zn^{68}, Zr^{90}, Zr^{94}, and In^{115} were reported. The cross-section values obtained in BGHR differed widely from the trend reported in a previous survey[2] (hereinafter referred to as PC), but since only four cross sections were measured, it was not possible to state conclusively whether the values obtained represented a new and different general pattern for (n,α) reactions, or whether they represented simply unusually large statistical fluctuations about the trend reported in PC. In the present paper, results of five additional (n,α) cross-section measurements are presented; these, together with the four measurements previously reported, indicate a trend substantially different from that reported in PC. Cross-section values obtained are typically about a factor of two lower than in PC at $A\approx 60$, and the factor gradually increases to about twenty at $A\approx 135$.

EXPERIMENTAL TECHNIQUE

As in BGHR, cross-section measurements were of a relative character, the actual measured quantity being the ratio of the (n,α) cross sections to the $Fe^{56}(n,p)$ cross section. From these cross-section ratios absolute values are derived assuming a value of 110 mb for the $Fe^{56}(n,p)$ cross section at 14 Mev. This value for the $Fe^{56}(n,p)$ cross section is an established mean value[3] based on measurements by PC (96.7 mb±12%) and by Forbes[4] (124 mb±10%). Subsequent to the establishment of the value given by reference 3, a measurement by Yasumi[5] (144±19 mb) has been reported. On the basis of reported measurements, the assumed value of 110 mb could be in error by +50% or by −20%, yielding a corresponding possible error in the absolute value of the cross sections reported herein. Errors given in the results are errors in the relative values only; any subsequent measurements of $Fe^{56}(n,p)$ leading to the firm establishment of a value different from 110 mb would require an appropriate change in the scale factor of all the cross sections herein reported. The relative relationships of the cross sections would, of course, be unaffected.

The substantial uncertainty in the absolute value of the calibration cross section is unfortunate; on the other hand, the detailed studies by Terrell and Holm[6]

* Operated for the U. S. Atomic Energy Commission by Union Carbide Corporation.

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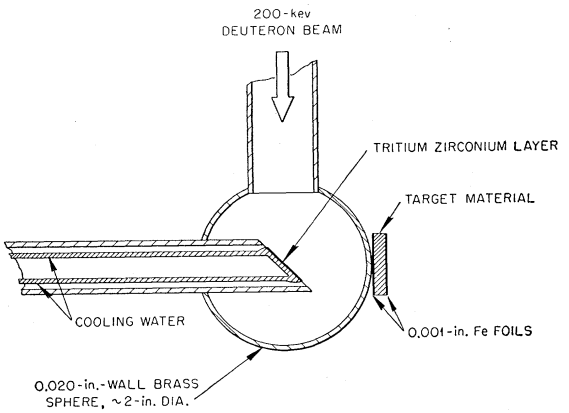

FIG. 1. Experimental arrangement showing the target and sample geometry. A detailed description is given in the text.

of the energy dependence of this cross section make it particularly suitable for use with a relatively inhomogeneous beam since effects of the inhomogeneities can then be corrected for. The half-life of the Mn^{56} activity is, moreover, ideal from the standpoint of experimental convenience and the decay mode and energy is very similar to that of a typical resulting (n,α) activity, thereby minimizing possible counting errors. These particular attributes of the $Fe^{56}(n,p)$ reaction from the standpoint of obtaining good relative cross-section measurements were deemed to outweigh the disadvantages incurred by the uncertainty in the absolute value of the cross section.

The details of the arrangement for activating samples are shown in Fig. 1. Deuterons of 200-kev energy from Cockcroft Walton Accelerator impinge on a "thick" zirconium tritide target producing neutrons via the $D(t,n)He^4$ reaction. Neutron yields were typically 10^{10} neutrons/second. The target is cooled from the rear by a thin water layer of thickness 0.020 in. and is housed inside a 0.020-in. thick brass sphere which forms the vacuum barrier for the accelerator. Samples consisted of a sandwich of the particular material being studied pressed between two pieces of 1-mil iron foil. Target materials were generally of a powdered form to facilitate dissolving; the complete sandwich was held together by a wrapping consisting of two layers of 1-mil aluminum foil. Target sandwiches (or samples) were $\frac{3}{4}$ in.$\times 1\frac{1}{2}$ in. in cross section, and were typically from 0.5 to 1.0 g/cm^2 in thickness. During activation, samples were centered on the equatorial plane defined by the incident beam and the zirconium tritide surface and at a radius of 1 in. The samples hence subtended a considerable range of colatitude in the laboratory system; correction for the center-of-mass motion and for the variation of total cross section with energy in the neutron-producing $D(t,n)He^4$ reaction[7] gives an effective neutron energy variation over the sample from 13.5 to 14.6 Mev. Possible further spread in the incident energy could be obtained from scattering of neutrons in the water layer cooling the target or from the brass sphere or from nearby equipment and shielding. To check on such possible degradation of the neutron spectrum, a photographic plate was exposed at a well defined colatitude angle and track lengths of elastically scattered recoil protons were measured in the emulsion. Approximately 25 tracks were followed in the plate; results displayed no detectable energy degradation due to scattering phenomena—hence, the source can effectively be considered as uniform in intensity over the 13.5 to 14.6 Mev range, and all cross-section values are averages over this energy interval.

After activation, target sandwiches were disassembled and the subject material was radiochemically processed to remove activities from elements other than that of the particular radioisotope being studied; chemical yields were determined by the addition of a known amount of carrier material before chemical processing. This then also resulted in samples after chemistry of approximately the same mass thickness as the 1-mil iron foils. Activation of the iron foils led to a pure 2.56-hour activity of considerable strength, so that it was necessary to count the iron only for a short period of time to determine its activity. Iron foils were counted during the chemical processing of the sample so that the sample could then be placed in identical geometry under the same counter and its decay followed for as long as desired. Decay curves from the chemically processed samples were most often a composite of a single activity plus background; the complexity of decay curves never exceeded two activities plus background.

From the observed relative activities, and knowing the number of atoms in both the iron foils and the original sample, the cross-section ratio can be straightforwardly determined. Counting corrections were made in the manner described by Blosser and Handley[8]; in

TABLE I. Observed values of the cross section for production of the isotope or isomer with indicated half-life by the (n,α) reaction at 14.05±0.55 Mev from the specified target nucleus. All values are relative to an assumed value of 110 mb for $Fe^{56}(n,p)$ at 14 Mev; stated errors, as indicated in the text, correspond to the uncertainty in the relative value of the cross section with respect to that of $Fe^{56}(n,p)$.

Target nucleus	Resultant half-life hr	$\sigma(n,\alpha)$ mb
Co^{59}	2.59	31 ±3.0
Zn^{68}	2.56	7.6±0.8[a]
Br^{79}	26.8	10 ±1.8
Zr^{90}	2.80	3.3±0.6[a]
Nb^{93}	61	9.0±2.2
Zr^{94}	9.7	3.6±0.5[a]
Pd^{108}	4.5	2.3±0.4
In^{115}	3.2	2.5±0.4[a]
Cs^{133}	12.6	1.0±0.3

[a] Previously reported in reference 1.

[7] J. L. Fowler and J. E. Brolley, Jr., Revs. Modern Phys. **28**, 103 (1956).

[8] H. G. Blosser and T. H. Handley, Phys. Rev. **100**, 1340 (1955).

addition, all sample materials were spectroscopically checked for impurities to insure that no possibility existed for a large cross-section reaction on an impurity giving a spurious activity.

RESULTS

The measured values of the (n,α) cross sections of the isotopes Co^{59}, Br^{79}, Nb^{93}, Pd^{108}, and Cs^{133} are given in Table I, along with the previously reported results from BGHR. The measurement errors quoted in Table I reflect the combined irreproducibility of results due to errors in the determination of chemical yields, counting statistics, errors in decay-curve analysis, etc., and, in addition, an allowance has been made for possible systematic errors arising in the counting corrections. As stated in an earlier paragraph, the quoted errors do not include any allowance for error in the assumed value of the $Fe^{56}(n,p)$ cross section; such an error would correspond to a shift in scale of the complete table; the indicated variation of the (n,α) cross section with mass number would be unaffected by such an error. These results are compared in Fig. 2 with results from PC. The marked difference between our results and those of PC is clearly indicated.

The chemical separation used in the present work avoids errors due to counting other reaction products along with the (n,α) product. PC used no chemical separation and their cross sections might, therefore, include contributions from other reaction products which in many cases have half-lives nearly the same as the (n,α) products. As mentioned in BGHR, two of the values reported therein are in good agreement with results obtained by Brolley *et al.*[9]

The two solid lines in Fig. 2 are empirical fits to our results for odd- and even-mass target nuclei, respectively. The (n,α) reaction on an even-even nucleus leads to an even-odd residual nucleus, while (n,α) on an odd-even nucleus leads to an odd-odd residual nucleus. The difference between the two solid lines is hence a crude measure of the difference in level density of odd-odd and even-odd nuclei, and is approximately a factor of two from these results.

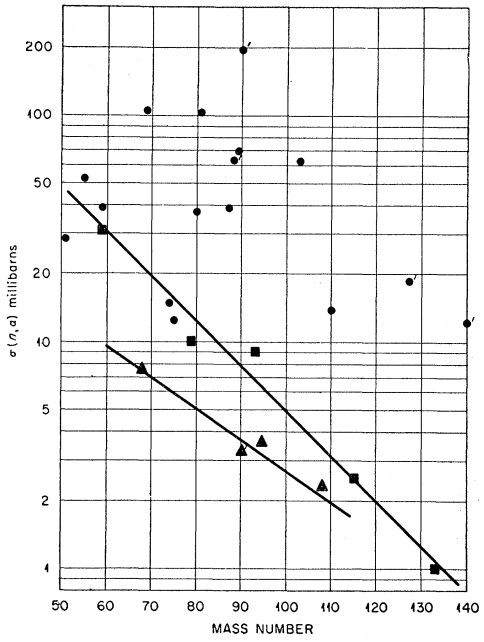

FIG. 2. Measured (n,α) cross sections plotted against mass number. ■—results from Table I for odd-mass target nuclei, ▲—results from Table I for even-mass target nuclei, ●—results from reference 2 for the mass region shown. Cross sections denoted by a prime indicate the measurement to be the cross section for production of only one of several known isomeric states of the residual nucleus.

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