The Cross Section for the Reaction $Al^{27}(\alpha,\alpha 2pn)Na^{24}$ from Threshold to 380 Mev*

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The cross section *versus* energy curve for the reaction $Al^{27}(\alpha, \alpha 2pn)Na^{24}$ has been determined from threshold to 380 Mev.

INTRODUCTION

THE formation of Na^{24} from Al^{27} by alpha-particle bombardment on the 184-inch Berkeley cyclotron has been reported by Helmholz and Peterson.[1] The excitation function was not published because of uncertainties in the contribution from the secondary neutrons via the $Al^{27}(n,\alpha)Na^{24}$ reaction and in the energy definition below 100 Mev.

The only information concerning the cross section for the reaction was made by Fung[2] by comparison of the Na^{24} yield with the yield from the reaction $C^{12}(\alpha,\alpha n)C^{11}$, whose cross section was presumed known.[3] However, such technique was neither direct nor free from uncertainties in the measurement of the latter cross section. An additional complication arises in that circulating helium-ion beams of the 184-inch cyclotron seemed inherently to be contaminated with varying amounts of deuterons in spite of usual pumping precautions.

A study was therefore undertaken of the energy dependence of the cross section for the reaction $Al^{27}(\alpha,\alpha 2pn)Na^{24}$. Considerable precautions were taken to use helium-ion beams known to be deuteron-free, and an attempt was made to establish the contribution of the $Al^{27}(n,\alpha)Na^{24}$ reaction to the observed yield of Na^{24}. The cross section was established by direct measurement at 380 Mev and also near the threshold.

EXCITATION FUNCTION FOR THE REACTION $Al^{27}(\alpha, \alpha 2pn)Na^{24}$

A. Experimental Procedure

In order to eliminate the possibility of deuteron contamination of the internal helium-ion beam of the 184-in. Berkeley cyclotron, the pulsed deflector was synchronized with the pulsed-arc helium-ion source. By this technique, beams when collimated, of approximately 0.01 microampere containing less than one percent deuterons were obtained.

The deflected beam was collimated with a brass block 1.5 inches thick containing a $\frac{3}{4}$-inch circular hole. The emergent beam then impinged upon a stack of aluminum absorbers, $2\frac{1}{2}$ in.$\times 2\frac{1}{2}$ in. in cross section. Five-mil aluminum foils, $2\frac{1}{2}$ in.$\times 2\frac{1}{2}$ in., were inserted at various distances within this stack in order to obtain the desired degraded alpha-particle energy. Beyond a thickness sufficient to stop helium ions of 400 Mev, was placed a similar aluminum stack thick enough to stop any deuterons which might have entered from the first stack. Five-mil foils were also interposed at various positions in this stack. Beyond this "deuteron stack" were placed several large absorbers which served to monitor the neutron flux. As in the alpha and deuteron regions of the stack, five-mil aluminum foils were used to measure the induced activity.

The three regions of the stacks were electrically insulated from each other by about $\frac{1}{2}$-inch of air and 10 mils of polystyrene foil. Electrical leads from the "alpha" and "deuteron" stacks were connected through shielded leads in the cyclotron probe to individual galvanometers in the control room. The entire block was covered by a copper R. F. shield.

After irradiation, circular disks of one-inch diameter were stamped from the irradiated five-mil foils in such a manner as to contain the entire alpha-activated areas. These disks were mounted on aluminum backing of thickness sufficient to give saturation back-scattering. The disks were designated as "centers," to distinguish them from the remainder of each of the five-mil foils, which were designated as the "exteriors." The "exteriors" were cut into rectangular quadrants and mounted on like aluminum backings, thus being counted under conditions approximating the same geometry as the "centers." All samples were counted with a Tracerlab type TGC-3A argon-filled G-M tube.

B. Experimental Results

The results of a typical experiment are shown in Fig. 1, in which the activity per unit thickness of foil is plotted as a function of absorber thickness. Curve A represents the "center" foils and curve B, the exteriors.

From the shape of curve A it can be inferred that all activity beyond the range of the alpha-particles must have been induced by the reaction $Al^{27}(n,\alpha)Na^{24}$ since the function in this region bears no resemblance to the $(d,\alpha p)$ function.[4] Curve B shows a constantly diminishing neutron background. Presumably, this neutron background in the exterior foils is due to (*a*) neutrons from the brass collimator, and (*b*) neutrons produced in the aluminum block itself. Beyond the range of the alpha-particles, the shapes of curves A and B are

* This work was performed under contract with the U. S. Atomic Energy Commission.
[1] A. C. Helmholz and J. M. Peterson, Phys. Rev. **73**, 541 (1948).
[2] Si-Chang Fung, Ph.D. thesis, University of California Radiation Laboratory Report UCRL 1465 (unpublished).
[3] V. Peterson and R. Phillips (private communication).
[4] Batzel, Crane, and O'Kelley (to be published).

similar, again suggesting that all activity in this region is neutron-induced.

Curve A, within the alpha-particle range, represents the combined production of Na^{24} from both alpha-particles and neutrons. In order to obtain the curve for alpha-induced activity alone, some estimate of the neutron background in the center foils had to be made. It was considered reasonable that this neutron background would be similar to that shown in curve B. Thus an extrapolation to zero absorber of the tail of curve A might represent this neutron background. This is shown by curve D. On the other hand, because of the unknown gradient of alpha-produced neutrons in the Al block, a crude constant neutron background such as is represented by curve E might be drawn. Curve C is an average of curves D and E and is the curve finally chosen to represent the neutron background. It must be emphasized that this choice introduces an inevitable indeterminancy in the resultant excitation function.

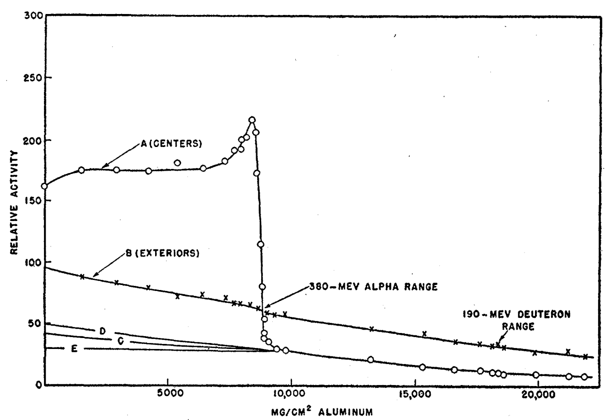

FIG. 1. Distribution of Na^{24} activity in aluminum stack.

It will be noted that the point at zero absorber appears low. This phenomenon occurred consistently and was attributed to a lower level of neutron-induced activity in the first "center" foil. Figure 2 shows the relative alpha-particle-induced activities of Fig. 1 plotted against the energy of the incident alpha-particle. No correction was made here for nuclear absorption. If one assumes an uncertainty in energy of 10 Mev at 380 Mev, this uncertainty becomes seriously magnified at lower energies as shown by the spread in the excitation function. Some such uncertainty in the exact alpha-energy is expected in the operation of the 184-in. cyclotron.

ABSOLUTE DETERMINATION OF THE CROSS SECTION OF THE REACTION $Al^{27}(\alpha, \alpha 2pn)Na^{24}$

A. Experimental Procedure and Results

In order to obtain the energy dependence of the cross section, the absolute cross section was determined at

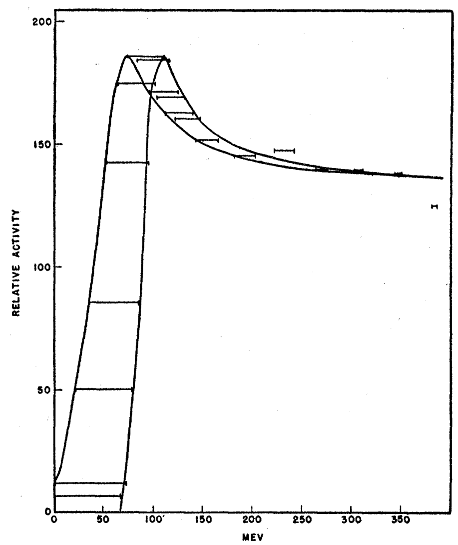

FIG. 2. Excitation function for the reaction $Al^{27}(\alpha, \alpha 2pn)Na^{24}$. Uncorrected for nuclear absorption.

380 Mev. In principle the method consisted of irradiating 5-mil aluminum foils in an external pulse-deflected $\frac{3}{4}$-in. collimated alpha-beam. The total charge passing through the foil was collected in a Faraday cup and measured with a conventional "slide-back" circuit.

The counting techniques were essentially those described in the excitation runs except that the disintegration rates were determined with a proportional counter of 100 percent geometry.

The results of two experimental runs yielded a cross section of 23.2 and 23.5 millibarns, respectively.

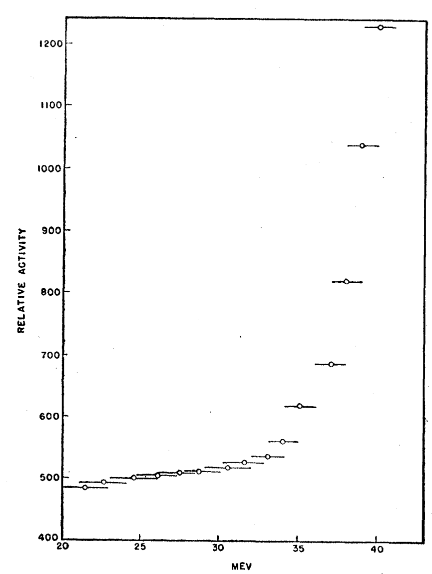

FIG. 3. Excitation function for the reaction $Al^{27}(\alpha,\alpha 2pn)Na^{24}$, including neutron-induced background.

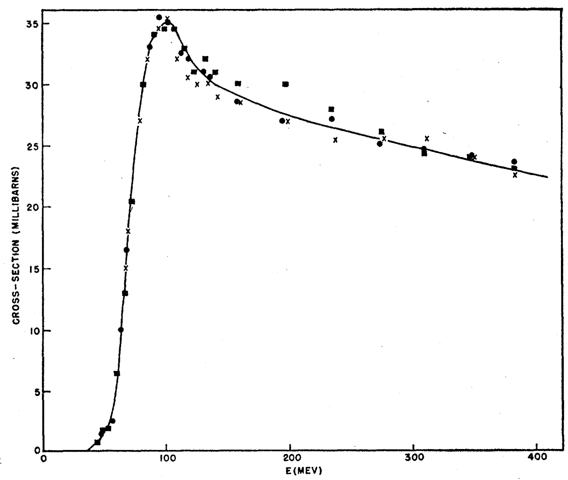

FIG. 4. Energy-dependence of the cross section for the reaction $Al^{27}(\alpha, \alpha 2pn)Na^{24}$. Circles, squares, and crosses indicate independent determinations.

DETERMINATION OF THE THRESHOLD FOR THE REACTION $Al^{27}(\alpha, \alpha 2pn)Na^{24}$

In order to obtain the excitation function accurately down to the threshold, the cross section *versus* energy was determined with the 40-Mev alpha-beam of the 60-in. cyclotron.

A. Experimental Procedure

Aluminum foils were mounted on a Faraday cup which fitted to the port of the 60-in. cyclotron. The charge collected in the Faraday cup was recorded on an integrator circuit. The sample mounting and counting techniques were the same as those described previously for the runs made with 380-Mev helium ions. Since the collimator on the 60-in. cyclotron was $\frac{1}{8}$-in. in diameter, and that in the 184-in. cyclotron $\frac{3}{4}$-in. in diameter, the effective sample size was different in the two cases. However, this effect on the counting geometry was negligible.

B. Experimental Results

Figure 3 shows the excitation function (including the neutron-induced Na^{24}) as a function of the alpha-particle energy. Table I gives the cross sections for the helium-ion induced activity as a function of the energy.

The observed threshold for the reaction may thus be taken at about 32–34 Mev. Of the three likely reactions $(\alpha,\alpha 2pn)$, $(\alpha,\alpha dp)$ and $(\alpha,\alpha He^3)$, the calculated thresholds are 36.1, 33.5, and 27.2 Mev, respectively. The first of these obviously cannot contribute to the lowest measured cross section; the second reaction, although at the threshold, should have essentially zero cross section because of barrier penetration considerations. Evidently the reaction producing the Na^{24} at 32–35 Mev must, therefore, be the $(\alpha,\alpha He^3)$ reaction. Since even at 40 Mev, i.e., 4 Mev above the $(\alpha,\alpha 2pn)$ threshold, the barrier penetration factors are extremely small, it is unlikely that the $(\alpha,\alpha 2pn)$ reaction is important. At higher energies, however, it is possible that all three reactions contribute to the formation of Na^{24}.

CROSS SECTION FOR THE $Al^{27}(\alpha, \alpha 2pn)Na^{24}$ REACTION FROM THRESHOLD TO 380 MEV

From the calculated cross section of 23.5 mb at 380 Mev, and from the excitation function of Fig. 2, it was possible to obtain σ *versus* energy. The uncertainty in energy, as shown in Fig. 2, was largely eliminated by plotting the values from Table I together with the values in Fig. 2. Although no "overlap" occurs in the results from the 184-in. and the 60-in. cyclotron experiments, a short extrapolation relates the two functions. It must be pointed out that there remains an inherent energy distribution of the alpha-particles on the 184-in. cyclotron. However, if this is ignored, the curve of Fig. 4 is obtained. The plotted values have been corrected for nuclear absorption of the alpha particles in the aluminum block. For this correction a cross section of 0.65 barn was used for aluminum and Beer's law was assumed applicable.

TABLE I. Cross sections for the reaction $Al^{27}(\alpha,\alpha 2pn)Na^{24}$ near threshold.

E	mb
39–41	0.28
38–40	0.20
37–39	0.11
36–38	0.058
34–36	0.033
33–35	0.012
32–34	0.002

We wish to thank the crews of both the 184-in. and the 60-in. cyclotrons of the University of California for bombardments which made this work possible, and G. D. O'Kelley for aiding in the electrical measurements. Thanks are also due to Miss M. Gallagher for technical assistance.