Excitation Curves for Reactions of Alpha Particles with C^{12} from 15 to 19 Mev*

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Exploratory measurements of the 4.43-Mev gamma rays from the reaction $C^{12}(\alpha,\alpha')C^{12*}$ and of the total cross section for the reaction $C^{12}(\alpha,n)O^{15}$ for incident energies between 15 and 19 Mev are reported. The two excitation curves appear somewhat anticorrelated, the maxima of the O^{15} yield occurring at 15.5, 16.6, 17.3, and 18.5 Mev, those of the gamma-ray yield at 15.9 and 18.0 Mev. There is no evident correlation between these curves and the differential (α,p) cross section reported by Priest, Tendam, and Bleuler.

IN studying the differential cross section for the reaction $C^{12}(\alpha,p)N^{15}$ as a function of the incident energy, both Nonaka *et al.*[1] (at 25 to 39 Mev) and Priest *et al.*[2] (at 16 to 19 Mev) found that the angular distribution for the ground-state protons indicates a direct-interaction mechanism, but is strongly energy dependent. The total cross section decreases smoothly with energy above 25 Mev, whereas there are indications of structure in the energy range investigated by Priest *et al.* (cf., Fig. 1). It may be possible that the results of Nonaka *et al.* can be explained in the framework of direct-interaction theories without introducing any energy-dependent parameters (as might arise from compound states),[3] but this appears difficult for the data at 16 to 19 Mev. If the structure of the compound nucleus influences these angular distributions, correlated variations might be found in the cross sections for other exit channels. In particular, Priest *et al.* found a pronounced maxima in the differential (α,p) cross section (for $\theta=31.8°$) at an energy of 17.5 Mev, with a width at half-maximum of about 1 Mev, and it appeared interesting to check whether any structure appears near this energy in the excitation curves for the (α,n) reaction and for the yield of 4.43-Mev gamma rays from inelastic scattering. Only exploratory measurements have been completed, but since the investigation cannot be continued presently, we wish to report the preliminary results.

EXPERIMENTS

The ~19-Mev alpha-particle beam from the cyclotron is focused by a pair of quadrupole lenses onto the entrance slit of a 55° wedge-type analyzing magnet. In taking the excitation curves, the analyzer was set to the desired energy, and the energy of the incident beam was reduced by placing Be and polyethylene absorbers in front of the analyzer entrance slit and adjusted by varying the cyclotron frequency and the deflector voltage over a small range. The approximate beam profile is shown in Fig. 1, insert A. The targets were polyethylene foils of 0.87-mg/cm² thickness, equivalent to about 350-kev energy loss of the incident alpha particles (see inserts B, C).

Gamma-Ray Yield

The gamma rays from the first excited state of C^{12}, excited by inelastic scattering, were measured with a NaI scintillation spectrometer, using a 20-channel pulse-height analyzer. The crystal, 3 in. in diameter, 2 in. long, was placed at 90° to the beam, the distance from the top of the crystal to the target center being about 2 in. The counter was shielded by a lead cylinder and all parts exposed to the beam in the vicinity of the counter were machined from bismuth or covered with lead, including the energy-defining aperture of the analyzing magnet and the Faraday cup. At each energy, the background pulse-height distribution, with target

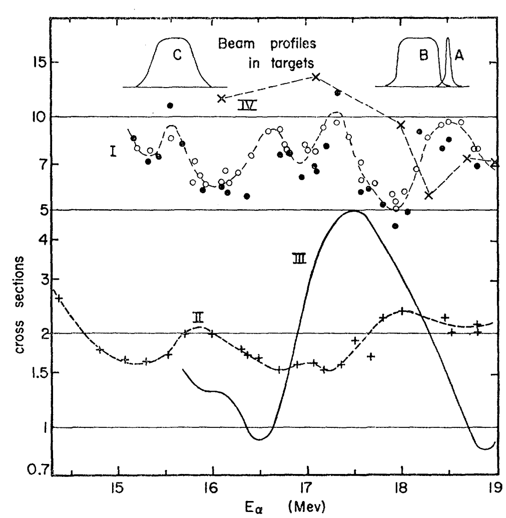

FIG. 1. Energy dependence of $C^{12}+\alpha$ reactions. I. Total cross section for $C^{12}(\alpha,n)O^{15}$, in mb. Full circles: first series; open circles: second series. Beam profiles: A—incident beam; B—first target; C—fourth target, for an incident energy of 18.5 Mev. II. Relative yield at 90° of 4.43-Mev gamma rays from $C^{12}(\alpha,\alpha')C^{12*}$. The beam profile for this curve is similar to B. III. Differential cross section for $C^{12}(\alpha,p_0)O^{15}$ at 31.8° (lab), in mb/sr, from Priest *et al.* The beam profile is about 30% wider than B. IV. The crosses show the cross section for $C^{12}(\alpha,p_0)O^{15}$, integrated from 20° to 170° (lab), in mb, from Priest *et al.*

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removed, was measured and subtracted. In the resulting pulse-height distribution, the intensity due to the 5.3-Mev gamma rays from the first excited state of N^{15} [from the (α,p) reaction] was subtracted and relative yields were calculated using the photo peak at 4.43 Mev and the one-escape peak at 3.92 Mev.

Production of O^{15}

The cross section for the (α,n) reaction was measured by observing the 124-sec positron activity of O^{15} using stacked foils. Because of the large energy of the O^{15} recoils, it was necessary to back each polyethylene target with three gold foils of about 1.5-mg/cm^2 thickness each. The stack exposed consisted of four such target assemblies, preceded by a 1.5-mg/cm^2 gold catcher foil to stop active recoil atoms, especially the 2.8-min P^{30} produced by the beam in the Al collimating hole. The energy loss of the beam in each target was about 800 kev; it was determined to an accuracy of about 30 kev by letting the beam pass through several target combinations into a broad-range spectrograph.. Inserts B and C in Fig. 1 show the approximate beam profiles in the first and the last target, the latter being calculated from the straggling formula given by Livingston and Bethe,[5] assuming uniform foils.

The activities were counted with four G. M. counters and followed for up to seven half-lives; there was no indication of any contamination. Since each bombardment yielded only four points of the excitation curve, several runs had to be made with different incident energies (in the range 17.7 to 19 Mev). In order to measure the effective beam charge, taking into account the decay of the activity during production, the current integrator[6] was modified by shunting the 5-μF integrating capacitor with a 35.8-Meg resistor so as to obtain a decay time equal to the mean life of O^{15}.

RESULTS

The results of these measurements, together with those of Priest *et al.*,[2] are shown in Fig. 1. As indicated (I), the measurements of the (α,n) cross section were done in two series which do not show complete agreement, but exhibit the same trends, with maxima around 15.8, 16.6, 17.3, and 18.5 Mev. The statistical uncertainty of the points is less than 3%, but there obviously are unknown sources of variations. The uncertainty of the absolute values of the cross section is about 25%, since the counters were not calibrated. Over most of the energy range, only the ground-state reaction is possible since the threshold for the 5.3-Mev first excited state of O^{15} is at $E_\alpha=18.4$ Mev. Our results, therefore, can be compared to the integrated (α,p_0) cross sections (IV); the two cross sections are seen to be of comparable magnitude. The gamma-ray yield (II, arbitrary units) shows rather less fluctuations than the (α,n) reaction, with maxima near 15.9 and 18.0 Mev, and a rise at the low-energy end. Since the accuracy of the individual points is estimated to be 3 to 4%, the rise indicated near 17 Mev is not significant.

CONCLUSION

The results of this study as shown in Fig. 1 may be summarized as follows:

(1) The energy dependence of the total cross sections measured is much less pronounced than that of the differential (α,p) cross section.

(2) No clear correlation exists between the differential (α,p) cross section (III) and either the gamma-ray yield from inelastic scattering (II) or the total (α,n) cross section (I).

(3) There might be an anticorrelation between the (α,n) cross section and the gamma-ray yield, the maxima of the latter coinciding approximately with the minima of the former.

(4) The 1-Mev width of the "resonance" of curve III is not generally representative of these excitation curves, as shown by the finer structure of the (α,n) cross sections. Measurements with thinner targets would obviously be desirable, as would be a more detailed determination of the energy dependence of the integrated (α,p) cross section.

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[6] Model CI-110, Eldorado Electronics, Berkeley, California.