A STUDY OF THE REACTION $^{12}C + ^{12}C$†‡

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The reaction $^{12}C + ^{12}C$ has been studied at an incident laboratory energy of 123 MeV. Angular distributions of the emitted α-particles and protons have been obtained. These angular distributions yielded values of $2\cdot6 \pm 0\cdot3$ barns, and $1\cdot5 \pm 0\cdot2$ barns for the total cross sections for α-particle and proton production respectively.

A beam of 123 MeV ^{12}C nuclei, produced by the Yale University heavy ion linear accelerator, was used to bombard a $1\cdot2$ mg/cm^2 polyethylene $[(C_2H_4)_n]$ foil. The scattering chamber and detector system were those described previously (Anderson *et al.* 1960). The detector consisted of a gas-filled proportional counter backed by a CsI(Tl) crystal and photomultiplier tube. The detection system was mounted on the rotatable lid of the scattering chamber and could be set at laboratory angles of observation between $8\frac{1}{2}$ and $171\frac{1}{2}°$. After passing through the target the beam current was collected in a Faraday cup and integrated. The number of incident particles for a given charge collected was calculated on the assumption that the ^{12}C nuclei were stripped bare of electrons in their passage through the target. They were accelerated in the 5+ charge state.

Pulses from the proportional counter, after suitable amplification, were sorted in size by a 4-channel analyser, whose outputs controlled a 400-channel analyser used as four separate 100-channel analysers. In this way the energy (E) pulses from the photomultiplier were sorted and recorded in channels appropriate to their sizes but also in blocks of 100 channels according to their rates of energy loss ($\mathrm{d}E/\mathrm{d}x$). The discriminator settings on the 4-channel analyser were set so that block one contained noise and high energy protons, block two low energy protons separated from high energy α-particles, block three α-particles, block four low energy α-particles separated from more intensely ionizing particles. This electronics system then served to separate protons and α-particles. Actually, deuterons and tritons would also be included in the proton spectra but similar studies with other heavy ion beams suggest that the contamination is less than 10% (Watson, personal communication 1961).

Energy calibrations of the system were made for α-particles by using a ThC, ThC′ source, and also by observing elastic and inelastic scattering of 41 MeV α-particles from carbon at various angles. At the same time the discriminator settings on the gating system were made to separate cleanly protons from

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α-particles. The presence of the hydrogen in the target material provided a source of recoil protons of known energy during this phase of the experiment. However, in the actual experiment, using the carbon beam, the presence of recoiling protons from the target material superimposed on the protons from the $^{12}C + ^{12}C$ reaction made a detailed analysis difficult. Hence, apart from total cross-section estimates, the data analysis was restricted to α-spectra. The reaction $^{1}H(^{12}C,^{4}He)^{9}B$ was observed at small angles but was easily separated off from the continuous spectrum of reaction α-particles.

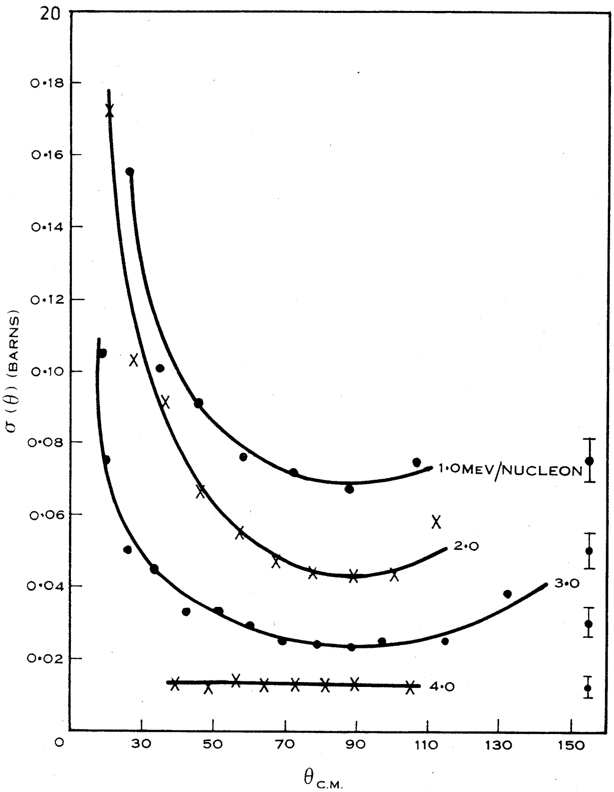

Fig. 1.—The angular distribution in the centre-of-mass system of α-particles from the bombardment of ^{12}C by 123 MeV ^{12}C nuclei.

The laboratory spectra were transformed to the centre-of-mass system of the colliding carbon nuclei. Figure 1 shows the results for α-particles of various energies. Because of the identity of the particles in the collision, symmetry about 90° in the centre-of-mass frame of reference is demanded. The data of Figure 1 show this symmetry and this fact tends to confirm that energy scales and data handling procedures are correct. In this reaction half the incident energy is used in motion of the centre of mass. Hence in the laboratory the reaction products are thrown forward strongly and it is difficult to observe the particles emitted at backward angles in the centre-of-mass system because of their low energy in the laboratory. Another consequence of the symmetry about 90° is that it is not possible to make the usual separation into direct processes and compound nucleus processes.

The data were analysed in terms of the simple statistical model by using the formula (Blatt and Weisskopf 1952)

$$N(E)\mathrm{d}E = \text{constant } E\sigma_c e^{-E/\theta}\mathrm{d}E,$$

where $N(E)$ is the number of particles of energy E per unit energy range, θ is the temperature of the residual nucleus in the reaction

$$^{12}\mathrm{C} + {}^{12}\mathrm{C} \rightarrow {}^{24}\mathrm{Mg}^* \rightarrow {}^{20}\mathrm{Ne} + {}^{4}\mathrm{He},$$

and σ_c the cross section for the inverse reaction. Values of σ_c were taken from optical model calculations (Igo 1959). That this simple treatment is inadequate is shown by the variation of the temperature with angle of observation. The data yield temperatures of 6·6 MeV to 9·0 MeV as θ_{cm} varies from 30 to 90°.

It is presumed that the simple analysis is inadequate in two respects: (*a*) angular momentum effects are ignored, (*b*) direct processes of the fragmentation type are believed to be important in complex nuclei interactions.

In order to investigate the reaction further, the opportunity was taken to make an estimation of the cross section for the production of particles heavier than α-particles. These data (Bromley and Sachs, personal communication 1961) were gathered by a method similar to that previously described (Anderson *et al.* 1960). The result was $0 \cdot 3 \pm 0 \cdot 1$ barns for heavy particles $(2 < E \leqslant 6)$. The principal contribution to this cross section is from inelastically scattered carbon nuclei.

The observed cross sections of 2·6 and 1·5 barns for α-particle and proton production are respectively 3·5 and 2 times the geometrical cross section for this reaction. In conjunction with the result for heavy particles, these figures are consistent with the reaction proceeding via two processes: (*a*) in 40% of the reactions one carbon nucleus is fragmented into three α-particles while the other carbon nucleus either survives the collision as an inelastically scattered particle or in a few cases is dissociated into two pieces each with atomic number between 2 and 6; (*b*) in the remaining 60% of the reactions four α-particles would be produced together with four protons and four undetected neutrons.

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