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SCATTERING OF 915-Mev α PARTICLES FROM CARBON AND HELIUM: DIRECT EVIDENCE FOR α-PARTICLE CLUSTERING IN NUCLEI*

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We have obtained direct evidence for α-particle clustering in C^{12} from the $(\alpha,2\alpha)$ reaction at 915 Mev. Measurements of the energies of the two outgoing α particles and the angular correlation between them show that the reaction proceeds via a direct collision between the incident α particle and an α-particle cluster in the nucleus. An estimate of the preformation probability has been obtained by comparing the carbon and helium differential cross sections.

Figure 1(a) is a diagram of the experimental arrangement. The 915-Mev α-particle beam from the Berkeley synchrocyclotron was focused at the center of an 18-in-diam. scattering chamber to a spot 1 in. wide by 3/4 in. high. The beam intensity was about 3×10^8 α particles per sec and was monitored by an 8-in.-diam. ionization chamber. The duty cycle was increased from about 60 μsec per burst to 12msec per burst by means of an extra peripheral dee. Measurements were made first with the chamber filled to 65 psi of helium and then with a thin graphite target (~ 260 mg/cm^2 for $\theta_L = 17$ deg and ~ 600 mg/cm^2 for $\theta_L = 26$ deg) placed at the center of the scattering chamber.

Particles scattered from the target were detected by counters placed at angles θ_L and θ_R with respect to the α-particle beam. The particles were identified by measuring their total energy, E, and their rate of energy loss, dE/dX. The dE/dX counters were discs of plastic scintillator 1.0 in. diam. by

0.1 in. thick, and the E counters were cylinders of plastic scintillator 3.5 in. diameter by 11 in. long. The response of the counters to α particles and protons of various energies was determined by placing the counters, preceded by an appropriate absorber, in the direct α particle and proton beams. The response was in reasonable agreement with calculations based on the response of plastic scintillator to lower-energy protons, deuterons, and electrons.[1] The nuclear absorption in the E counters was about 35% and was determined in the direct beam by measuring the low-energy tail of the pulse-height spectrum.

A block diagram of the electronics is shown in Fig. 1(b). The fast-coincidence resolving time was 5 nsec and was limited by the flight-time difference between high- and low-energy α particles leaving the target. The particle-selection systems consisted of complex arrangements of discriminators and coincidence circuits acting on linear outputs from the dE/dX and E counters. In this way, we were able to sort doubly charged particles (He^3 and He^4) from singly charged particles with a high degree of reliability. Outputs from the particle selection systems were fed into a slow-coincidence unit which was used to start a magnetic recorder. With the helium target, the fast-coincidence counting rate was typically one per second, whereas the $(\alpha,2\alpha)$ coincidence rate was only one per minute. Outputs from the E counters were pulse-height analyzed in the magnetic recorder. In addition, information concerning the energy range in which each α particle fell was recorded. The magnetic tape was subsequently analyzed using an IBM 7090 computer.

The differential cross section $d^2\sigma/d\Omega_1 d\Omega_2$ for scattering of the α-particle beam by helium and carbon was measured at $\theta_L = 17$, 26, and 45 deg, with $\theta_L + \theta_R = 87$ deg (the separation angle for elastic scattering at 915 Mev). At each angle, we measured the energy spectrum E_L and the spectrum of the sum of the energies $E_L + E_R$.

The spectra from helium at 17 deg are shown in Fig. 2. The peak at 815 Mev in E_L and 915 Mev in (E_L+E_R) corresponds to the elastically scattered group. The second peak at E_L= 650 Mev and (E_L+E_R)= 750 Mev is thought to be due to stripping of the forward-going α particle into a He^3 plus a neutron. The relative intensities of these two peaks are misleading, since the elastic peak is sharply correlated at these angles, whereas the inelastic group would be expected to have a broader distribution. The third peak may be due to an energy cutoff in the experiment at around 350 Mev. The energy calibration throughout these measurements is uncertain to ± 50 Mev. At 26 deg the spectrum looked essentially the same but the cross section was reduced. The cross section at 45 deg was too low to be measured.

The carbon data at 26 deg is shown in Fig. 3. The summed spectrum again shows two peaks, but the relative intensity of the elastically scattered group appears reduced. This is because the angular correlation is broadened by the momentum distribution of the α particles in the carbon nucleus. The peak at 750 Mev in the energy spectrum E_L for events with $E_L+E_R > 850$ (i.e., the elastically scattered group) shows clearly that the reaction is proceeding via a direct collision of the α particle with an α cluster in the nucleus. If, for instance, the initial collision was between the incident α particle and a deuteron, then the energy of the α particle scattered at 26 deg would be about 500 Mev. An α-particle--nucleon collision producing an α particle at 26 deg is kinematically forbidden.

Further evidence in support of this conclusion is given in Fig. 4 which shows the summed spectra for θ_L= 17 deg and $\theta_L+\theta_R$ equal to (a) 87 deg and (b) 57 deg. The intensity of the elastically scattered group drops by about a factor of four when the separation angle is moved 30 deg from the kinematic angle of 87 deg. Consequently, the recoil α particle is correlated to within 6 ± 3% of the total available solid angle.

In order to obtain the probability of α-particle clustering in carbon, the differential cross sections for elastic scattering from helium and quasi-elastic scattering from carbon have been calculated at 17, 26, and 45 deg and are shown in Table 1. The differential cross section for helium has been corrected for the finite size of the beam, the finite extent of the helium gas target, and nuclear absorption in the counters. To obtain the cross section for carbon, one must integrate over the solid angle into which the correlated α particle can be scattered.

Table 1. The differential cross sections for elastic scattering from helium and quasi-elastic scattering from carbon.

θ_L (deg)	$d\sigma/d\Omega$ (μbarns/sr)		$\frac{d\sigma/d\Omega \text{ (carbon)}}{d\sigma/d\Omega \text{ (helium)}}$
	Helium	Carbon	
17	165±35	287±150	1.7±0.9
26	22±11	86± 50	3.9±2.9
45	~ 0	~ 0	----

To perform this integration, we have assumed that the angular correlation follows a triangular distribution through the two experimental points, that the angular correlation at $\theta_L = 26$ deg is the same as $\theta_L = 17$ deg, and that the width of the distribution out of the plane of scattering is the same as that in the plane of scattering. The large errors on the cross sections quoted in Table 1 are primarily due to the inadequacy of the data on the angular-correlation function.

The ratio of the $(\alpha,2\alpha)$ differential cross section for carbon and helium is 1.74 ± 0.9 at 17 deg and 3.9 ± 2.9 at 26 deg. According to the extreme α-particle model for carbon, we would expect this ratio to be about 3.

Further measurements are in progress on the angular-correlation function and the differential cross section for the $(\alpha,2\alpha)$ reaction for other nuclei.

We wish to acknowledge Mr. Charles A. Corum for designing the scattering chamber, Messers Melvin Brown and Ellwood S. Douglas for assistance with the electronics, Dr. Paul Concus for the computer program, and the crew of the 184-in. cyclotron for their cooperation.

REFERENCE

1. T. J. Gooding and H. G. Pugh, Nuclear Instr. and Methods 7, 189 (1960).

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FIGURE LEGENDS

Fig. 1(a) Diagram of the experimental arrangement.

(b) Block diagram of the electronics.

Fig. 2. Scattering from helium at $\theta_L = 17$ deg, $\theta_L + \theta_R = 87$ deg:

(a) summed energy spectrum $E_L + E_R$

(b) energy spectrum E_L. The energy calibration is uncertain to ± 50 Mev.

Fig. 3. Scattering from carbon at $\theta_L = 26$ deg, $\theta_L + \theta_R = 87$ deg:

(a) summed energy spectrum $E_L + E_R$

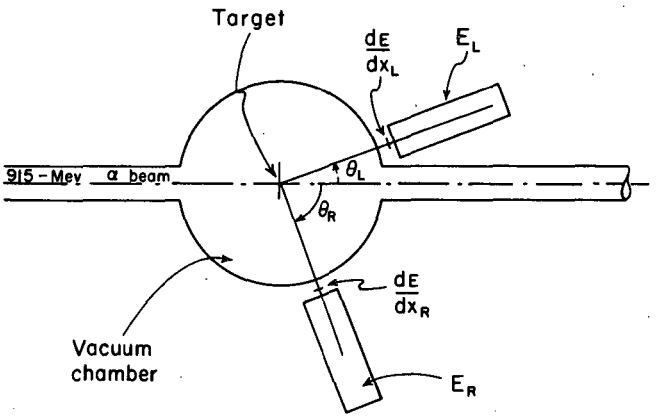
(b) energy spectrum E_L, where $E_L + E_R > 850$ Mev. The energy calibration is uncertain to ± 50 Mev.

Fig. 4. The carbon summed energy spectrum at $\theta_L = 17$ deg and

(a) $\theta_L + \theta_R = 87$ deg

(b) $\theta_L + \theta_R = 57$ deg. The energy calibration is uncertain to ± 50 Mev.

(a)



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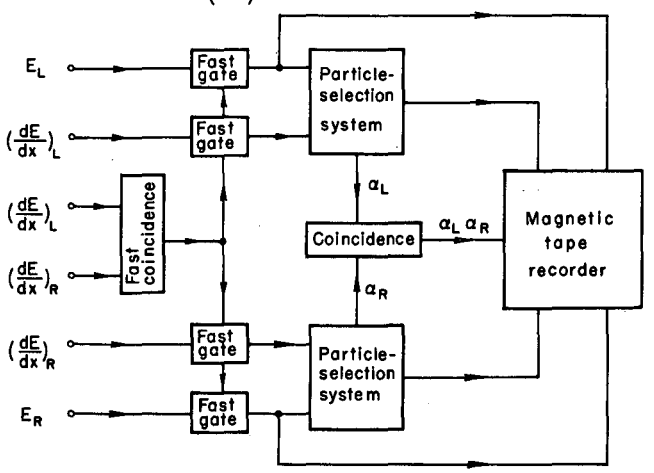

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Fig. 1

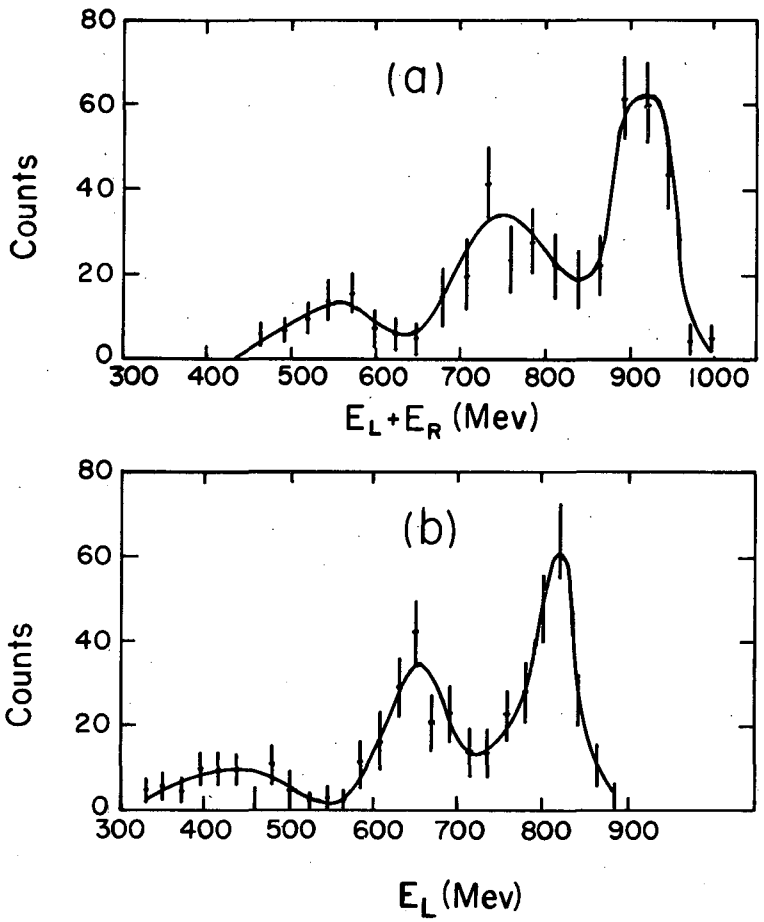
(a)
Counts
80
60
40
20
0
300
400
500
600
700
800
900
1000
$E_L + E_R$ (Mev)
(b)
Counts
80
60
40
20
0
300
400
500
600
700
800
900
E_L (Mev)
MU-23565

Fig. 2

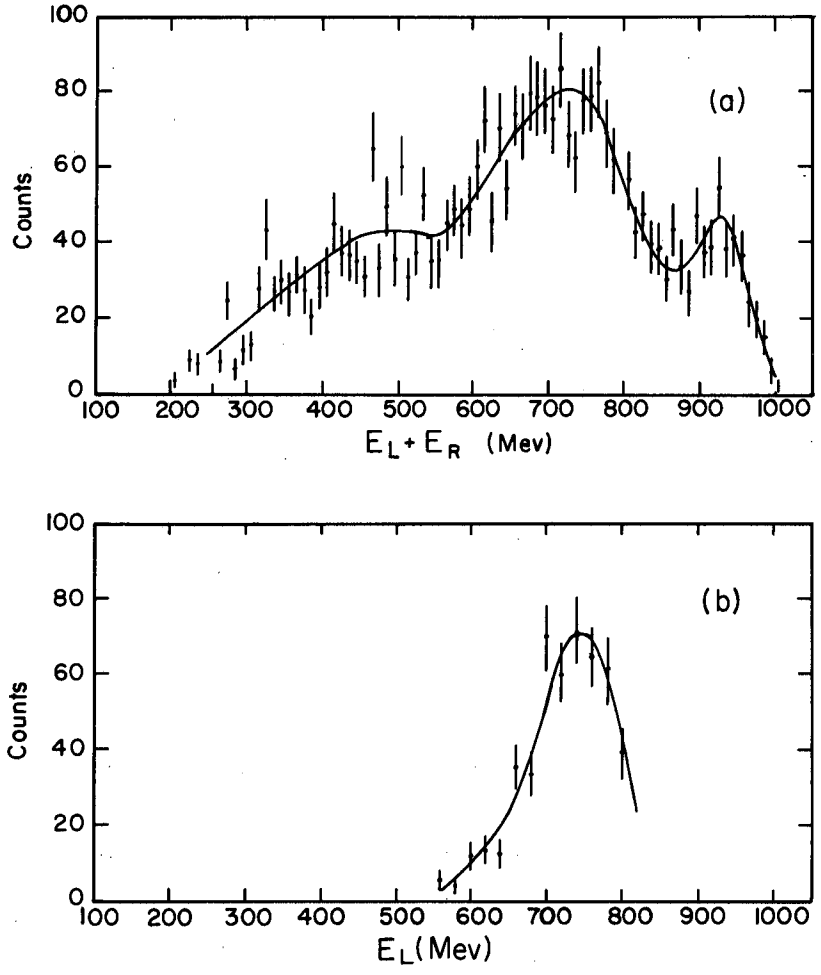

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Fig. 3

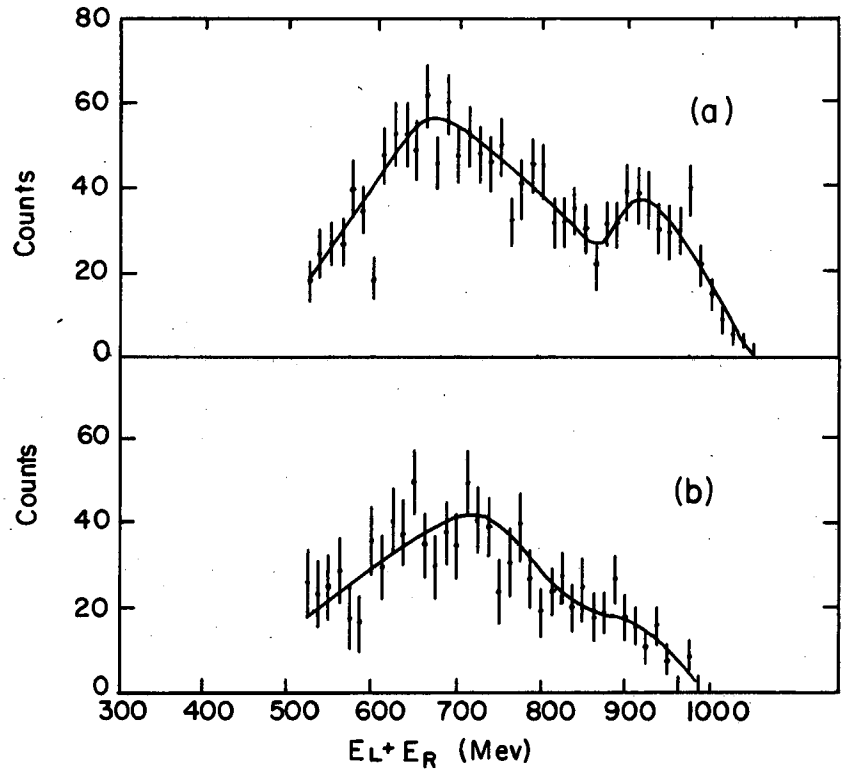

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Fig. 4