INVESTIGATION OF THE C^{12} $(\alpha, 4\alpha)$ *REACTION*

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The disintegration of the C^{12} nucleus induced by 23-Mev α particles into three α particles is investigated. Space and energy distributions of the decay products as well as excitation energies of the possible intermediate nuclei C^{12*} and Be^8 are presented. It is established that the basic reaction mechanism is the decay of the O^{16} nucleus into four α particles with a resonance interaction between the final-state α particles.

THE disintegration of the C^{12} nucleus into three α particles induced by 23-Mev α particles can proceed by various mechanisms through various energetically possible channels. The present study attempted to analyze the relative probability of these different mechanisms by methods adopted in our preceding investigations of light nuclear decays.[1-4]

Alpha particles were accelerated in the 120-centimeter cyclotron of the Research Institute for Nuclear Physics of the Moscow State University. Extracted from the cyclotron chamber through a system of quadrupole lenses and a deflecting magnet into the experimental room, they entered a chamber containing photographic plates (in a special cassette) inclined at an angle of 6° to the incident beam. Exposures of tenths of a second were used. Stars formed in the emulsion by the incident 23 ± 1-Mev α particles and by α particles from disintegrations were observed in NIKFI photographic plates (types Ya-2, T-1, T-3, and D, from 50 to 400 μ thick). The decay of C^{12} nuclei in the emulsion was observed, and from the resultant stars the energy and emission angle of all α particles produced in the reaction as well as the energy of the incident α particles could be computed. All data were transformed into the center-of-mass (c.m.) system. About 100 stars resulting from the disintegration of C^{12} nuclei induced by 23 ± 1-Mev α particles were found among the stars analyzed.

The following mechanisms for the α-particle induced decay of a C^{12} nucleus into three α particles are possible:

$$C^{12} + \alpha \to O^{16*} \to C^{12*} + \alpha \to Be^8 + 2\alpha \to 4\alpha, \quad (1)$$

$$C^{12} + \alpha \to O^{16*} \to C^{12*} + \alpha \to 4\alpha, \quad (2)$$

$$C^{12} + \alpha \to O^{16*} \to Be^8 + Be^8 \to 4\alpha, \quad (3)$$

$$C^{12} + \alpha \to O^{16*} \to Be^8 + 2\alpha \to 4\alpha, \quad (4)$$

$$C^{12} + \alpha \to O^{16*} \to 4\alpha, \quad (5)$$

$$C^{12} + \alpha \to C^{12*} + \alpha \to Be^8 + 2\alpha \to 4\alpha, \quad (6)$$

$$C^{12} + \alpha \to C^{12*} + \alpha \to 4\alpha. \quad (7)$$

The first five mechanisms involve decay through the compound system O^{16}. The last two involve the decay of the C^{12} nucleus into three α particles as the result of a direct interaction between the incident α particle and the nucleus.

In order to determine the probabilities of these mechanisms, the distributions of excitation energy of the intermediate nuclei C^{12} and Be^8, as well as the α-particle angular and energy distributions, were investigated. It was noted when processing the stars that certain of them contained pairs of α particles with very small angular divergence. This fact suggested the possibility that a Be^8 nucleus in the ground state was involved in the reaction. To test this hypothesis, the energy distribution of all possible values of excitation energy for the Be^8 nucleus was plotted as calculated from the energies of and angles between the α particles. Since four α particles are produced in each event, it was necessary to consider six possible values of Be^8 excitation energy $[E_{excit}(Be^8)]$ for each star.

The $E_{excit}(Be^8)$ distribution obtained is shown in Fig. 1a. It must be kept in mind that out of six $E_{excit}(Be^8)$ values for each decay event two can have a physical sense, since two intermediate Be^8 nuclei can be produced at a time. If the intermediate Be^8 nucleus takes part in the decay of C^{12} into three α particles, maxima corresponding to known levels of the Be^8 nucleus must appear against the background of a continuous distribution of $E_{excit}(Be^8)$ values. As can be seen from Fig. 1a, the ground and 2.9-Mev levels of Be^8 do appear in the distribution, and there is also an indication that the well-known broad level in the 8—14-Mev interval is involved in the decay.

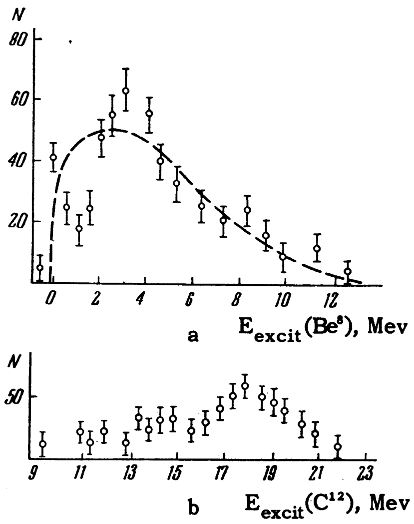

FIG. 1. Excitation energy of possible intermediate nuclei from $C^{12}(\alpha, 4\alpha)$ reaction induced by 23±1-Mev α particles: a – Be^8 nucleus, b – C^{12} nucleus.

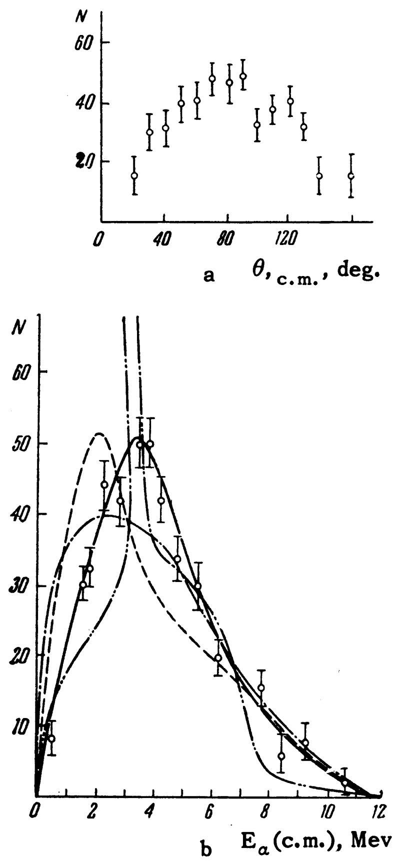

FIG. 2. Distribution (c.m.) of α particles from the reaction $C^{12}(\alpha, 4\alpha)$ induced by 23±1-Mev α particles: a – angular distribution, b – energy distribution.

In order to examine the possibility that the C^{12} nucleus decayed into three α particles through channels (1) and (2), excitation energies of the C^{12} nucleus were computed from the energy of the three α particles resulting from the decay of the intermediate nucleus C^{12}. Since it was impossible to determine which three of the four α particles produced in the reaction could have resulted from the decay of the C^{12} nucleus, its excitation energies were calculated from all possible combinations of three from the four α particles. Thus, if the reaction proceeded via mechanisms (1) or (2), the true values of $E_{excit}(C^{12})$ had to be weighted by $\frac{1}{4}$.

The distribution of $E_{excit}(C^{12})$ values is presented in Fig. 1b, from which it is evident that maxima corresponding to known C^{12} nuclear levels are not observed. If the intermediate nucleus C^{12} had actually been involved in the decay, its 9.6-Mev level with zero isotopic spin should have appeared as a maximum against the background of false $E_{excit}(C^{12})$ values (Fig. 1b). This level stands out far enough from neighboring levels and, as has been shown by the authors in a study of the decay of the C^{12} nucleus induced by 10–19-Mev neutrons,[5] this level can appear when the C^{12} nucleus decays.

Therefore, mechanisms (1) and (2) may be considered as not very probable for the given decay. Moreover, if the C^{12} nucleus decayed into three α particles by mechanism (2), that is, the intermediate Be^8 nucleus was not involved in the decay, the $E_{excit}(Be^8)$ distribution (Fig. 1a) should have been described by a curve calculated for mechanism (2) by a method used earlier.[2] This curve is plotted in dashes on Fig. 1a. Its disagreement with the experimental data is sufficient testimony to the improbability of the reaction having occurred via mechanism (2).

The angular distribution of α particles from the reaction is presented in Fig. 2a. As is visible from the graph, this distribution is symmetrical with respect to 90° within the limits of statistical accuracy, which indicates the absence of a direct interaction mechanism in the decay. This conclusion is confirmed by the absence of a high-energy "tail" in the energy distribution of the α particles (Fig. 2b).

We examine next mechanisms (3), (4), and (5), which have to do with the decay of the compound system O^{16*} into two, three, or four particles respectively. The probability of these mechanisms occurring can be determined by investigating the energy distributions of the α particles produced in the reaction. If the reaction proceeds via a direct decay of the compound system O^{16*} into four independent particles, the energy distribution of the α particles must obey the following relation

$$F(E_\alpha) = E_\alpha^{1/2}(E_{max} - \mu E_\alpha)^{1/2},$$

where E_α is the α-particle energy, E_{max} is the maximum α-particle energy, and μ is the mass coefficient. The curve plotted from this formula is presented in Fig. 2b by the dot-dashed line (one dot). No agreement with experiment is observed.

If the compound system O^{16*} decays into two Be^8 nuclei which then decay into two α particles each, it is possible to construct a distribution of α particles from the Be^8 decay in the center-of-mass system of all the products formed. In doing so we must consider the fact that both Be^8 nuclei may be produced in the first excited state, or one may be in the ground state and the second in the first excited state. A curve that takes into account the probability of Be^8 nuclear levels appearing is plotted in a dot-dashed line (two dots) in Fig. 2b.

The case of two Be^8 nuclei being formed in the ground state was not considered in the calculations. If the O^{16*} system decays into two Be^8 nuclei in the ground state, the star formed by the α-particle tracks in the emulsion will have the characteristic form of two pairs of grouped tracks. After transforming into the center-of-mass system, it becomes possible to separate out such stars. There were none of them among the stars we observed. A comparison of the two-dot dot-dashed curve with experimental results shows that mechanism (3) is improbable.

The probability of mechanism (4) occurring can be investigated by comparing the experimental energy distributions of α particles with the curve calculated assuming a three-particle decay of the O^{16*} system into two α particles and a Be^8 nucleus in the ground or first excited state (taking into account the probability of appearance of the Be^8 nuclear states). The theoretical curve is plotted in dashes in Fig. 2b. In this case the agreement with experimental data was likewise not good.

Let us examine one other possible way for light nuclei to decay into several particles which has not been considered in earlier studies, namely, the simultaneous decay of the compound system into particles which interact in the final state. In this case we will have the decay of O^{16*} into four α particles resonantly scattering on the levels of the Be^8 nucleus. The solid line in Fig. 2b represents the curve calculated using this hypothesis by the method given in [4]. As can be seen from the graph, the experimental data are in good agreement with this calculation.

We may thus conclude that the decay of the C^{12} nucleus into three α particles induced by α particles proceeds with high probability through the direct decay of the compound system into α particles which interact in the final state. The intermediate nucleus Be^8 appears in this decay as the result of the resonance interaction of the final-state α particles from the simultaneous decay of the compound system O^{16*}. From this it is clear why, when the Be^8 excitation energy distribution (Fig. 1a) indicated a large probability that this unstable nucleus should appear, the disintegration actually proceeded with low probability by mechanisms (1), (3), (4) and (6), which involve states of the intermediate Be^8 nucleus.

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[5] Vasil'ev, Komarov, and Popova, JETP **33**, 1321 (1957), Soviet Phys. JETP **6**, 1016 (1958).

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