EMISSION OF THREE α PARTICLES IN INTERACTIONS BETWEEN B^{10} IONS AND LIGHT NUCLEI

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Interactions of 100-MeV B^{10} ions with light emulsion nuclei were studied. The use of given sensitivity, comprehensive measurements of the stars, and a detailed kinematical analysis of the interactions have made it possible to identify reactions (1)—(4). The cross sections for these reactions, averaged over the B^{10} incident energies between 30 and 90 MeV, were determined.

INTERACTIONS of heavy ions with atomic nuclei characteristically involve a large variety of nuclear reactions. One of the possible types of nuclear reactions produced by heavy nuclei is a reaction involving the transfer of one or a cluster of nucleons from one of the colliding nuclei to the other. [1] The new nuclei can be formed in the ground state or in strongly excited states. In the interaction of heavy ions with light nuclei, one or both of the colliding nuclei can disintegrate into individual nucleons (if the excitation energy is sufficient), α particles, or other strongly bound clusters of nucleons. [2] The mechanism of these reactions has not yet been fully investigated.

At the present time, there is a firm basis for the opinion that the correlation between nucleons on the surface of the nucleus is much stronger than inside it. [3] The emission of clusters of nucleons should occur primarily from the nuclear surface, since the mean free path of these clusters in nuclear matter is small. In the case of light nuclei, for which the ratio of the surface layer to the total volume is much greater than in the case of heavy nuclei, these facts should have particularly important consequences.

The present experimental study of cross sections for interactions of B^{10} ions of energy between 30 and 90 MeV with the light nuclei (C, N, O) of emulsion included the following reactions:

$$C^{12} + B^{10} \rightarrow B^{10} + 3\alpha - 7.3 \text{ MeV}; \quad (1)$$

$$N^{14} + B^{10} \rightarrow C^{12} + 3\alpha + 7.6 \text{ MeV}; \quad (2)$$

$$O^{16} + B^{10} \rightarrow N^{14} + 3\alpha - 2.8 \text{ MeV}; \quad (3)$$

$$N^{14} + B^{10} \rightarrow 6\alpha + 0.36 \text{ MeV}. \quad (4)$$

Reactions of a similar type can be studied with the aid of nuclear emulsion or scintillation ionization chambers which permit the simultaneous detection of all charged products of the nuclear reactions.

These measurements are part of a broad program to study interactions of heavy ions with emulsion nuclei.

Pellicles of NIKFI-D nuclear emulsion 400 μ thick were exposed to 100-MeV B^{10} ions from the multiply-charged-ion linear accelerator of the Physico-technical Institute of the Ukrainian Academy of Sciences. The B^{10} ions entered the emulsion at an angle of 25° relative to the surface. The use of emulsion made it possible to reliably separate tracks produced by singly charged particles from those produced by doubly charged particles and heavier nuclei. Since the initial energy of the ions was known, the energy at which the reaction took place could be determined from the distance traversed by the B^{10} ion.

From a total of more than 3000 stars produced in interactions of B^{10} with emulsion nuclei, we selected about 300 stars in which three α particles and one heavier nucleus (four-prong stars) were emitted and several stars in which six α particles (six-prong stars) were emitted. Comprehensive measurements of these stars and the subsequent detailed kinematical analysis of each star made it possible to identify the nucleus (C, N, or O) in which the reaction proceeded and the type of reaction which produced the star.

The kinematical analysis included the following:

a) The kinetic energy of the possible reaction products was compared with the kinetic energy of the B^{10} ion at the time of the reaction. The energy released in the reaction was taken into account here.

b) For each prong we determined the polar angle and compared the B^{10} momentum at the time of the reaction with the projection of the momenta of the possible reaction products in the direction of the B^{10} ion.

c) For each prong we determined the azimuthal angle and compared the projections of the momenta of the possible reaction products on a plane perpendicular to the direction of the incident ion.

If in the first two steps of the kinematical analysis the energy and momentum of the possible reaction products were equal to the energy and momentum of the incident B^{10} ion, then in the last step we analyzed only the momenta of these reaction products and in this way we eliminated the uncertainty in the initial energy and momentum of the B^{10} ion.

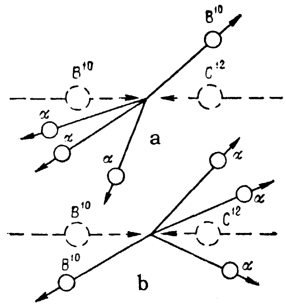
The measured cross sections for these reactions averaged over the B^{10} bombarding energies from 30 to 90 MeV are given below:

Reaction	Cross section, mb
$C^{12} + B^{10} \rightarrow B^{10} + 3\alpha - 7.3$ MeV	80^{+20}_{-10}
$N^{14} + B^{10} \rightarrow C^{12} + 3\alpha + 7.6$ MeV	100^{+40}_{-20}
$O^{16} + B^{10} \rightarrow N^{14} + 3\alpha - 2.8$ MeV	50^{+20}_{-10}
$N^{14} + B^{10} \rightarrow 6\alpha + 0.36$ MeV	20^{+30}_{-10}

For a small group of four-prong stars (three α particles and one heavier nucleus), it was difficult to make an unambiguous choice between two reactions on the basis of the kinematical calculations for the interaction. These stars were not taken into account in the estimate of the cross sections, but were included in the measurement errors. Among this group were stars in which one of the prongs escaped from the emulsion (the kinematical analysis of such stars is difficult). This also led to asymmetric errors. The errors in the cross sections listed above also include errors in the determination of the number of incident B^{10} ions and the number of C, N, and O nuclei in the emulsion.

The maximum energy of the B^{10} ions was 100 MeV. However, in view of the fact that the reactions produced by ions of energy between 95 and 100 MeV take place close to the emulsion surface and have an appreciable probability of yielding one or several prongs which escape from the emulsion, this energy interval was excluded from the considerations. In no case was it found that a reaction of the type considered was produced by B^{10} ions of energy below 30 MeV.

In the study of stars due to the reaction $C^{12} + B^{10} \rightarrow B^{10} + 3\alpha$, we noted two different types of stars. In one case all α particles were emitted in the backward hemisphere in the c.m.s., while the B^{10} nucleus was emitted in the forward hemisphere (see Fig. a); in the other case, the α particles were emitted in the forward hemisphere, while the B^{10} nucleus was emitted in the backward hemisphere (Fig. b). The first type of star is, of course, due to grazing collisions of B^{10} with C^{12} nuclei. The B^{10} ion imparts to the C^{12} nucleus a fraction of its kinetic energy, which proves to be sufficient for the disintegration of the C^{12} nucleus into α particles. In the second case, it is likely that the deuteron is transferred from the C^{12} nucleus to the B^{10} ion to form another C^{12} nucleus, which then splits into α particles.



Two types of stars from the $C^{12} + B^{10} \rightarrow B^{10} + 3\alpha$ reaction (in the c.m.s.). The initial directions of the B^{10} and C^{12} nuclei are shown dotted.

The selection of stars by means of a kinematical analysis involves the assumption that all the reaction products are in the unexcited state (the sum of the kinetic energies of the possible reaction products is equal to the kinetic energy of the incident B^{10} ion after the energy of the reaction is taken into account); therefore the suggestion that the C^{12} nucleus breaks up as a result of a frontal collision with the B^{10} ion should, in all probability, be rejected, for it is difficult to believe that, as a result of a frontal collision of two nuclei, one of the nuclei remains in an unexcited state, while the excitation of the other is quite large. It is most probable that as a result of a frontal collision both colliding nuclei are strongly excited. In the transfer reaction, the new B^{10} nucleus can be formed in an unexcited state.

It should be mentioned that in all the investigated reactions involving capture of a deuteron or α particle one of the newly formed nuclei breaks up into α particles. All the foregoing reactions appear to involve a common interaction mechanism. However, in order to clear up this question each reaction has to be studied in detail.

The cross section for the reaction $C^{12} + B^{10} \rightarrow B^{10} + 3\alpha$ can be compared with the data of Miller on the disintegration of C^{12} ions into three α particles in collisions with emulsion nuclei; these data are given in Fremlin's survey.[5] The cross section for the disintegration of C^{12} in emulsion is 49–66 mb.

It is of interest to compare the cross section for the $N^{14} + B^{10} \rightarrow 6\alpha$ reaction with the cross section for the $C^{12} + C^{12} \rightarrow 6\alpha$ reaction.[2] The cross section for the latter reaction, averaged over the corresponding interval of excitation energies in the c.m.s., is 50—60 mb, i.e., practically of the same order as the cross section for the reaction $N^{14} + B^{10} \rightarrow 6\alpha$. This fact, perhaps, will serve as an indication that the α-particle correlation of nucleons originates with a large probability not only on the surface of unexcited nuclei, but at the instant of the interaction of two colliding nuclei when the excitation energy is quite large.

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