Observation of a decay (fission) of relativistic ^{24}Mg and ^{28}Si nuclei into two fragments of approximately equal charge

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The decays of relativistic nuclei Mg→B + N and Si→C + O, resulting from inelastic peripheral interactions, have been observed in a nuclear emulsion.

Whether fission can occur in the region of light nuclei has been discussed in the literature for several years now.[1–5] The experiments which have been carried out by the various methods ($\Delta E - \mathrm{E}$ telescopes, ionization chambers, and polycarbonate films) have usually detected a single fragment; the characteristics of the second fragment of the target could be inferred only indirectly. The data have not been very reliable because of the low kinetic energy of the decay products. The cross sections which have been reported are contradictory.

The least ambiguous way to identify a reaction of this sort (at an accuracy to within neutral particles) is by means of nuclear emulsions, with the decaying entity moving at a high velocity. In this letter we examine some experimental data obtained during the bombardment of photoemulsion chambers containing the emulsion BR-2, of relativistic sensitivity, by means of light nuclei with momenta from 4.1 to 4.5 GeV/c per nucleon at the synchrophasotron of the Joint Institute for Nuclear Research. A search for inelastic interactions of ^{24}Mg and ^{28}Si ions in these emusion layers revealed isolated events of a decay of an incident nucleus into only two fragments with approximately equal charge and with small transverse momenta (without any further emission of charged particles). These events were similar to cases of in-flight fission of relativistic ^{238}U nuclei which had been observed previously[6] by an emulsion method.

Among the 2757 and 4155 inelastic interactions of ^{12}C and ^{22}Ne and nuclei which had been processed earlier, not a single event of this sort had been found. The fact that such decays are observed for the nuclei ^{24}Mg and ^{28}Si in a smaller statistical base (1666 and 1900 disintegrations, respectively) implies a possible increase in the probability for this reaction mechanism with increasing mass number and charge of the nuclei.

The charges of the fragments were determined by measuring the density of δ-electrons. When conservation of charge is taken into account, this method is accurate within 0.2 of a charge unit. It was found that the following disintegrations occurred: (1) Mg→B + N and (2) Si→C + O. The results of precise angular measurements are shown in Fig. 1, in the plane perpendicular to the direction in which the incident nucleus is moving. The angles are given in degrees. The errors are no longer than the points. Here θ is the polar angle at which the secondary fragment is emitted, reckoned from the direction in which the incident nucleus is moving; φ is the projection of θ onto the horizontal (XY) plane; α is the projection of θ onto the vertical (XZ) plane;

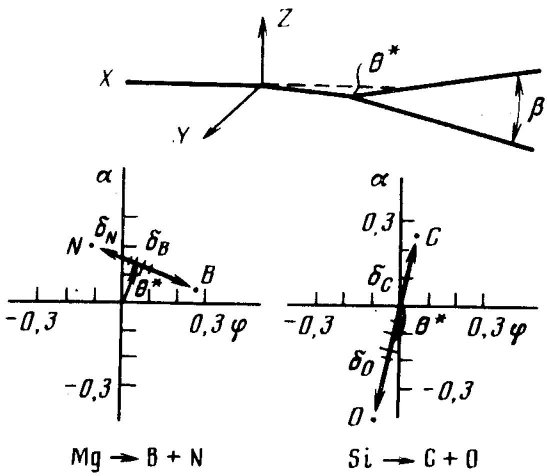

FIG. 1. Angular diagram.

and β is the angle between the fragments. In this coordinate system the X axis runs along the direction of the primary track.

To determine the disintegration products kinematically, we worked from the assumption that the excited system decays into only two fragments. The angle (β) betwen the fragments [0.352 ± 0.004 and 0.670 ± 0.016 for cases (1) and (2), respectively] must be broken up into two angles δ in inverse proportion to the masses of the fragments, as follows from the equality of the transverse components of their momenta, $p_\perp$. In this manner we can determine the angle θ^* (Fig. 1), which is the angle of the initial deflection of the incident nucleus as it interacts with a nucleus of the emulsion. We can therefore find the momentum transfer p_t in this collision (280 ± 20 and 260 ± 40 MeV/c, respectively). As a result, the incident system is excited and decays. The absence of a track of the recoil nucleus at such values of the transverse momentum indicates that these collisions occur with nuclei of the heavy component (AgBr) of the emulsion.[7] The error in the determination of the quantities $p_{t,\perp}$ results primarily from the uncertainty in the isotopic composition of the fragments. The short line segments in the figure show the possible range of positions of the decay point, while the long segments show the most probable range, i.e., that determined for the nuclides which have the greatest yields in the fragmentation reactions.[8,9]

From the values of the angles δ we can find the perpendicular component of the momentum of these fragments, $p_\perp$ [160 ± 5 and 320 ± 15 MeV/c for cases (1) and (2), respectively], and we can find a lower limit on their kinetic energy in the rest frame of the decaying nucleus: $T_B = 1.35 \pm 0.05$ and $T_N = 1.05 \pm 0.05$ MeV for reaction (1) and $T_C = 4.70 \pm 0.25$ and $T_0 = 3.60 \pm 0.35$ MeV for reaction (2). For the events which are being analyzed here, the sum of the kinetic energies of the fragments does not exceed the height of the Coulomb barrier for such decays (7.7 ± 0.8 and 10.1 ± 1.0 MeV, respectively). This result does not contradict the assumption that the kinematics of the products of these disintegrations, as in the fission of heavy nuclei, is determined primarily by the height of the Coulomb barrier. On the other hand, a corresponding kinematic analysis of nucleus-nucleus interactions, in which there are charged particles other than the two fragments of the incident nucleus with $z \geqslant 3$, shows that in more than 80% of the cases the resultant total kinetic energy (more precisely, the lower limit on it) is well above the height of the Coulomb barrier.

The energy yield (Q) of the decay of ^{24}Mg and ^{28}Si into stable isotopes of B, C, N, and O and into isotopes lying near these stable isotopes falls between 11 and 36 MeV. The fission barriers for the corresponding decays into modes with the lowest value of Q are 35–45 MeV, according to calculations in the liquid-drop model.[10] Consequently, disintegrations of the nature of a fission of light nuclei do indeed occur and can be observed at low excitation energies, on the order of 50–70 MeV. The cross sections for these processes can be about 1 mb.

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