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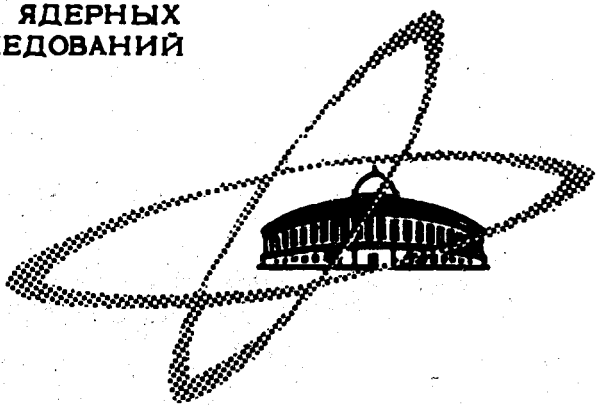

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EVIDENCE FOR INTERMEDIATE MECHANISM IN INTERACTIONS BETWEEN COMPLEX NUCLEI

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1. Introduction

Interaction between complex nuclei can be divided into three different groups:

1) long range interactions (Coulomb scattering, Coulomb excitation, tunneling neutron transfers)

2) direct interactions in surface collisions (nuclear elastic and inelastic scattering, nucleon transfer reactions)

3) compound nucleus processes.

Surface collisions of complex nuclei may be treated in the quasi-elastic approximation, because the excitation energy and the angular momentum transferred in such processes amount to only a small fraction of the total kinetic energy and the total angular momentum of the colliding nuclei[1-6].

The second well known mechanism of the interaction between complex nuclei is the formation of a compound nucleus.

For low energies of incident ions the two above mentioned mechanisms are sufficient to explain the total reaction cross section. However, when the incident particle energy increases the cross section for the compound nucleus formation decreases [7], and the decrease can not be compensated by a rather slow increase of the reaction cross section for the "quasi-elastic" processes [8,4]. One can, therefore, expect that at sufficiently high energies an "intermediate interaction mechanism", which has not been studied so far, will play an important role. It seems to be obvious that this intermediate interaction mechanism should appear mainly in the reactions proceeding with high excitation energies.

In the present work the reactions: (^{16}O,F), (^{16}O,Ne) and (^{16}O,Na) on the ^{27}Al, ^{51}V and ^{93}Nb target nuclei were studied. The energy of the ^{16}O ions beam was 137, 126 and 131 MeV, respectively for the reactions on the three above mentioned target nuclei. Therefore, the reactions proceeded at approximately the same value of $E_{CM} - B_{CM} \approx 67.5$ MeV, where E_{CM} is the initial kinetic energy and B_{CM} is the height of the Coulomb barrier at $R = r_0 (A_1^{1/3} + A_2^{1/3})$, $r_0 = 1.5$ fm.

Experiments were performed on the U-300 cyclotron of the Laboratory of Nuclear Reactions, JINR.

The identification of the reaction products was carried out by measuring the particle stopping power ΔE and the total energy E with the help of two semiconductor detectors. The width of the thin ΔE detector was equal to 10 μm. The ΔE and E pulses were analyzed by two-dimensional 4096-channel analyzer.

2. Experimental results and discussion

The energy spectra of the pick-up ($^{16}O, F$), ($^{16}O, Ne$) and ($^{16}O, Na$) reaction products on ^{27}Al, ^{51}V and ^{93}Nb target nuclei were measured for several angles. In the case of the reaction on aluminium the Mg nuclei were also detected. The different isotopes of F, Ne, Na and Mg were not separated. This, however, is not essential for our conclusions.

Figures 1, 2 and 3 show the energy spectra of the investigated reaction products. The arrows on these figures denote the energy values corresponding to the transfer reactions in which the final reaction products are left in the ground states. One sees that only in the fluorine spectra the peak characteristic for "quasi-elastic" transfers occurs. On the contrary, the multinucleon reaction products are not observed in the energy region corresponding to the typical direct interaction processes.

Another characteristic feature is the occurence of a well pronounced maximum in the energy spectra in the energy region corresponding to high excitations of the order of a few tens of MeV. This maximum is best pronounced in the reactions on the heaviest of all irradiated targets, namely on ^{93}Nb. With the exception of small angles, this maximum is predominant in the energy spectra. It should be pointed out that this maximum manifests itself equally well in the pick-up and in the stripping reactions. Nevertheless, we investigated in detail only the pick-up reactions, because an unambiguous interpretation of the stripping reactions is difficult (the products of the dissociation and the stripping-type transfer reactions would not differ when the continuous spectrum is measured).

Below we give the qualitative interpretation of the observed energy spectra.

It is known that the compound nucleus can not be formed for the angular momentum higher than some critical value ℓ_{crit} /9-11,7/. It is also known that typical transfer reactions are surface interaction processes, which proceed at a very narrow interval of the angular momentum values $\ell_{graz} \pm \Delta\ell$ /8,4/. So, for sufficiently high energies there exists a comparatively wide region $\ell_{crit} < \ell < \ell_{graz}$, in which the formation of the compound nucleus is not possible and at the same time the classical impact parameter is smaller than the sum of interacting nuclei radii leading to excitation of many degrees of freedom. One can therefore expect that the interaction in the intermediate region $\ell_{crit} < \ell < \ell_{graz}$ will proceed with high excitations. The essential part of the excitation energy evidently appears as the excitation of the collective degrees of freedom, mainly the rotational ones.

In the interaction process the colliding nuclei can interchange nucleons and then the interacting system decays into two or more fragments.

If we consider the two-body decay of the interacting system, the decrease of the kinetic energy of the outgoing particle for a given angle corresponds to the increase of the excitation energy. Fig.4 shows that high excitation energies should appear for small impact parameter, for which strong interaction between nucleons of the two colliding nuclei takes place. In this case the transfer of a given group of nucleons is more probable. One should therefore expect a monotonic decrease in the energy spectra of the reaction products with increasing energy (fig.4). However, in the case of the two-body decay of the interacting system there exists a limit on the spectra from the low energy side, caused by the existence of the Coulomb barrier for this decay. If the decay into two fragments

$(Z_1 A_1)$ and $(Z_2 A_2)$ takes place, then the energy of the detected product $(Z_1 A_1)$ in the centre of mass system should be higher than the threshold value

$$E_{CM}(Z_1 A_1) = \frac{A_2}{A_1 + A_2} \cdot \frac{Z_1 Z_2 e^2}{r_0 \cdot (A_1^{1/3} + A_2^{1/3})} .$$

In the spectrum of the reaction products a peak should therefore appear, situated a little bit higher than the threshold energy (fig.4). It should be pointed once more that this shape of the spectrum should be expected only for two-body interaction in the intermediate region $\ell_{crit} < \ell < \ell_{graz}$.

In the energy spectra measured by us, except for the lowest outgoing angles, we indeed observe maxima, which are situated some MeV higher than the calculated threshold energies (in figs.1, 2, 3 the threshold energies, transformed to the laboratory system are marked as a dashed, vertical lines).

For low angles the energy spectra extend much lower than the threshold energies. Evidently, in this region of angles the decay into more than two fragments plays an important role. The comparison of the reaction products spectra obtained on different targets shows that the process with the production of three (or more) fragments is stronger in the reaction on the ^{27}Al target than on the heaviest targets. Particularly, the magnesium and sodium spectra from the $^{16}O + ^{27}Al$ reaction for small angles can not be explained in the frame of the two-body mechanism.

The number of reaction products with the energies below the threshold energy decreases with the increase of the outgoing angle. The appearance of the maxima situated above the threshold energy gives evidence for the intermediate interaction mechanism outlined above. This two-body mechanism, together with the processes of decay into three or more particles plays evidently an impor-

tant role in the interactions between complex nuclei in the intermediate region of the angular momentum $\ell_{crit} < \ell < \ell_{graz}$.

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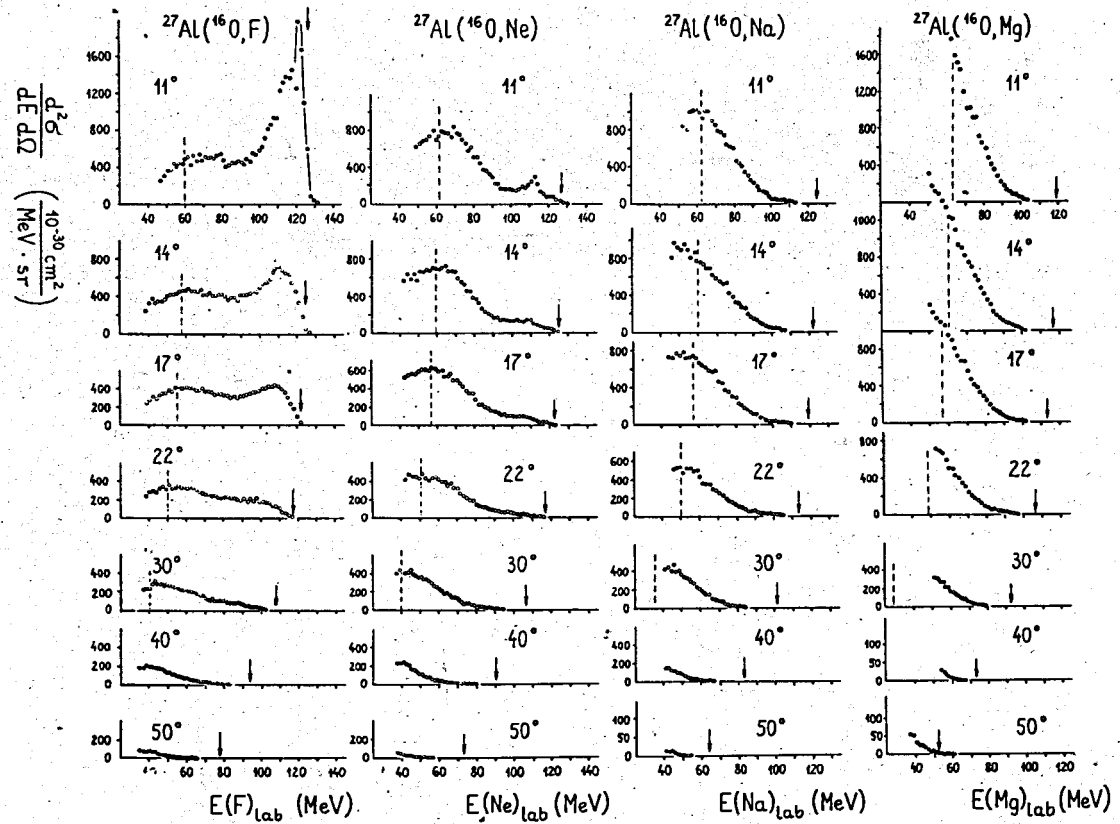
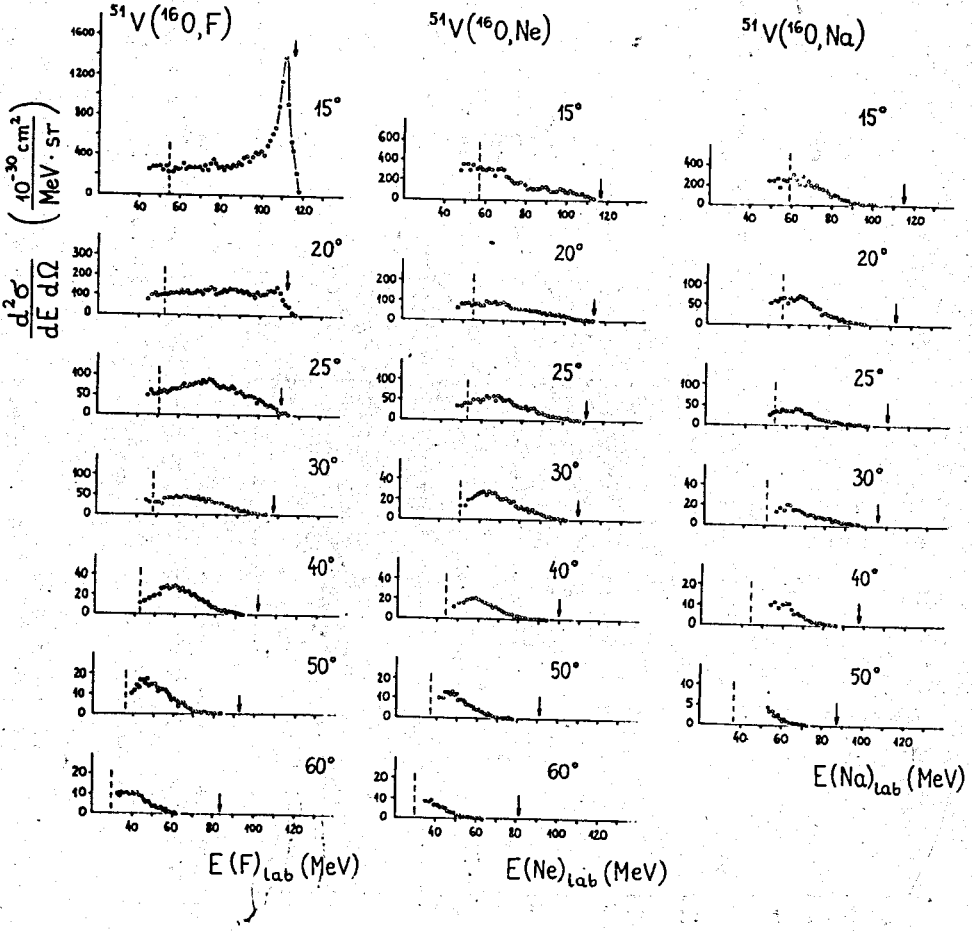
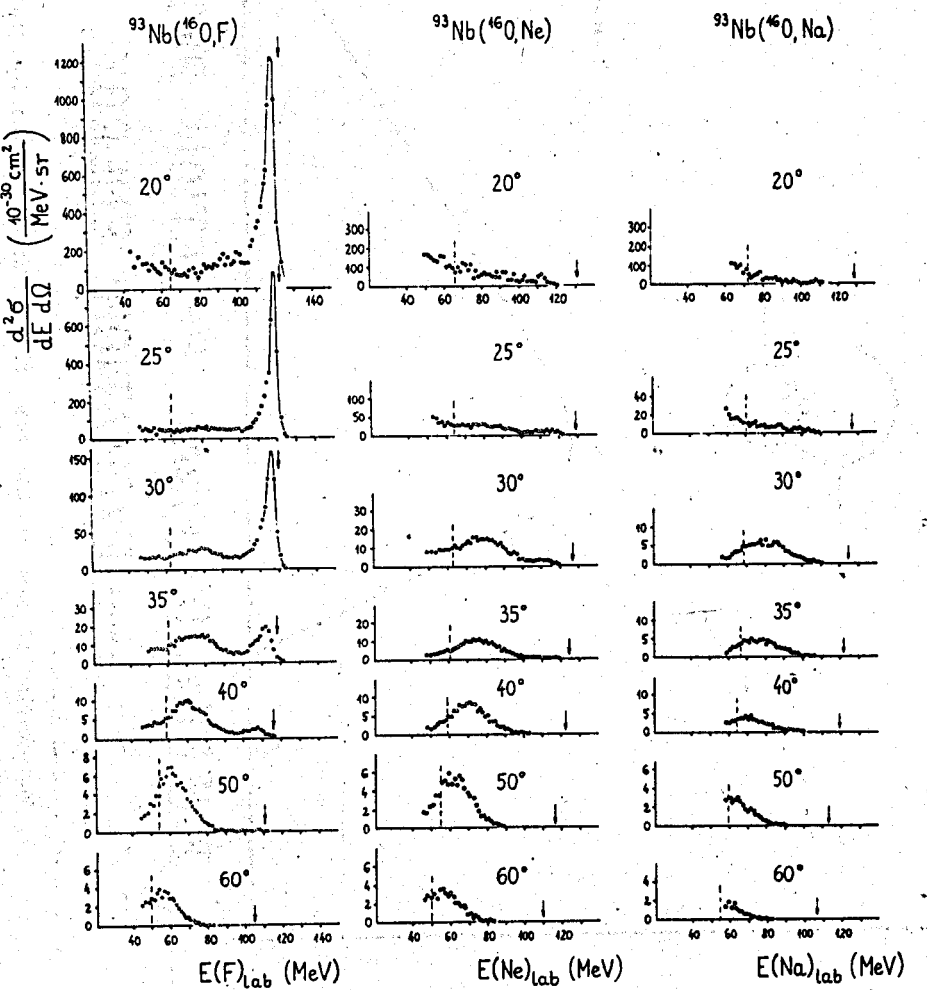


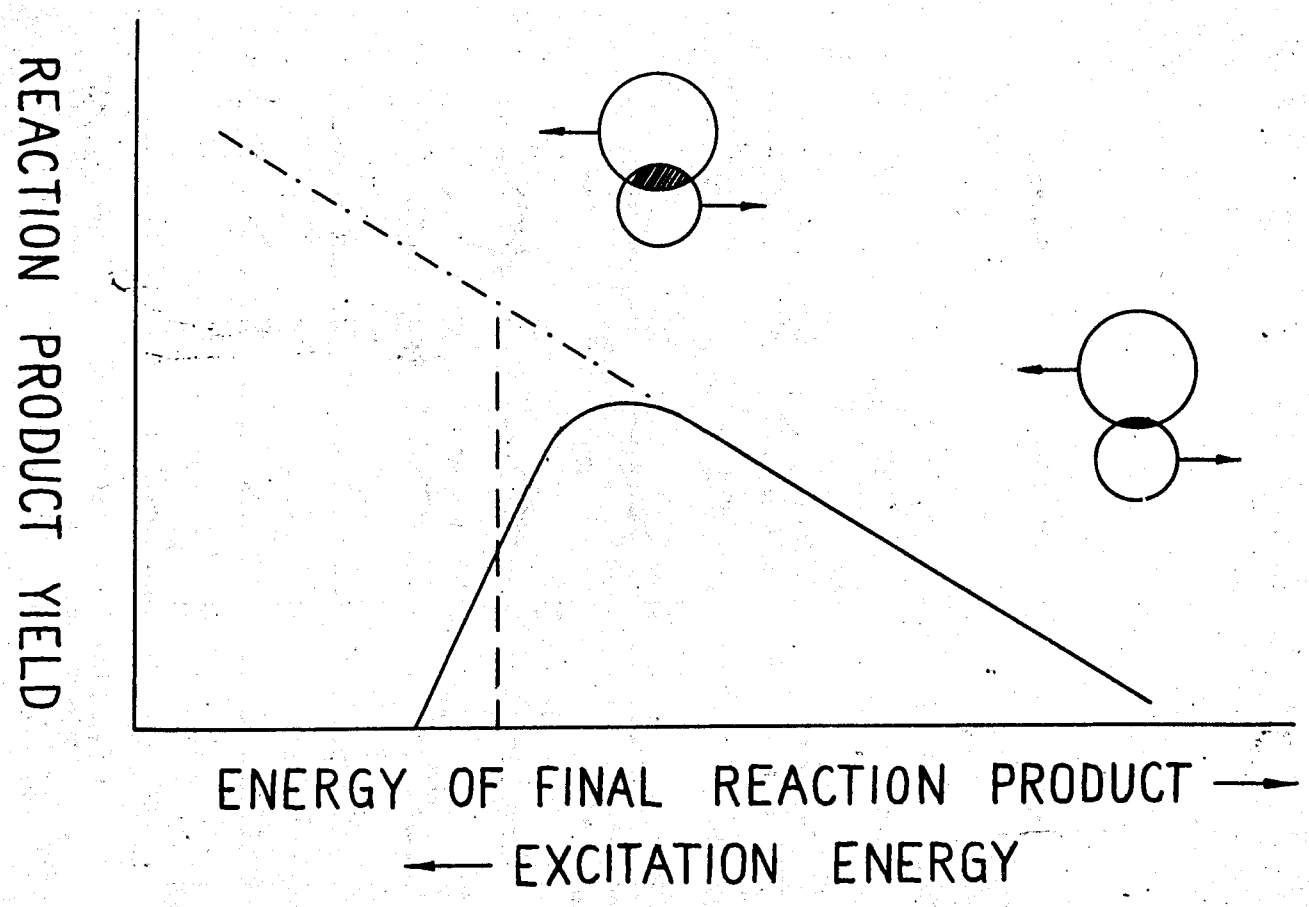
1. Energy spectra of F , Ne , Na and Mg reaction products from the $^{16}O + ^{27}Al$ reaction at E_{LAB} = 137 MeV.



2. Energy spectra of F, Ne and Na reaction products from the $^{16}O + ^{51}V$ reaction at E_{LAB}=126 MeV.



3. Energy spectra of F , Ne and Na reaction products from the $^{16}O + ^{93}Nb$ reaction at $E_{LAB} = 131$ MeV.



4. Schematic picture of the energy spectrum shape for the two-body reactions in the intermediate region of angular momentum.