On cluster model of heavy nuclei fission

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This research is made within the framework of the cluster approach and is stimulated by the absence of a satisfactory dynamic model of low-energy heavy nuclei fission. The fission process model taking into account the distinguished role of definite nucleon configurations was suggested rather long ago in /1/. The basic assumptions were formulated as following postulates: (1) the fission takes place with a significant probability if two cluster structures (A_h=132amu and A_l=84amu) are not broken into fragments; (2) the nucleons outside these clusters form a neck with an equal probability of rupture along its length; (3) the contributions of light clusters to the mass distribution of fragments are additive. This model failed to provide adequate quantitative description of the experimental mass distributions whereas the qualitative analysis supported, as stated in /2/, the hypothesis about two fission modes - purely cluster one and liquid drop mode. The technical difficulties in cluster model calculations prevented one from necessary detalization of this approach.

In the last few years some new data supporting the significance of cluster-type correlations were obtained in the heavy ion emission studies and nuclear reactions with light alpha-cluster nuclei. We'll note here only some following results. In ref./3/ the microscopic wavefunction approach was used to calculate the possibility of the existence of ^{14}C nucleus structure in ^{226}Ra nuclei. The decay width was shown to be proportional to the degree of pre-formation for an open decay channel in the parent nuclei or the spectroscopic factor S. In its turn, S is proportional to the overlay integral between states in the emitted fragment ^{14}C and the highest states of ^{223}Ra. In fission studies the pre-formation mechanism was noted in several experiments /4-6/ where the decay channels of ^{24}Mg were studied at different methods and energies of excitation. The fissile yields for alpha-cluster fragments decay were shown to contradict the statistical model predictions. On the contrary, they are in favor of highly clustered states in ^{24}Mg with large prolate deformation (the axis ratio 2:1), that is as if the ^{24}Mg nuclei in this minimum were formed by two adjoining ^{12}C spheres. In this case the spectroscopy factor is obviously displayed. One can ground a more general assumption that the cluster configurations are fully correlated with local minima on the potential energy surface calculated within the shell model /7/.

One more major generalization of numerous experiment results on decay of excited light alpha-cluster nuclei is the empiric "threshold rule", formulated by K.Ikeda /8/. According to this rule, the light alpha-cluster nucleus (for example ^{20}Ne) at some threshold value of excitation is clustered to alpha-particle and the corresponding nucleus-remainder (^{16}O) and so on until the complete decomposition of initial nuclei into alpha-clusters. As Ikeda formulated in /8/, in the low-excitation region of light nuclei the cluster structure and the shell-model structure coexist as "two kinds of fundamental structure inter-penetrating and coupling each other". There are some indications, discussed in following, that this assumption seems valid not only for the light nuclei. The neutron multiplicity dependence data on the fragment kinetic energy E_k /9/ may serve as basic point for the new model. These data show that the fragments with closed shell N=50 and Z=50 are "born" undeformed in the whole range of measured E_k and corresponding range of pre-scission configurations. One can logically adopt the saw-tooth Terrell's curve (neutron multiplicity $\nu(A)$) as the measure of N=50 and Z=50 cluster stability towards fissile system excitation, originated from dissipation as well as introduced from outside. The minima in $\nu(A)$ curve define the masses of spherical clusters A_h and A_l. So, for ^{235}U thermal fission one obtains A_h=130 amu, A_l=82amu with the possible error of 1-2 amu from the experimental accuracy in $\nu(A)$ /11/.

Taking into account all above-mentioned factors, the possible development of fission process for low-energy heavy nuclei may be described as follows (taking for example ^{236}U nuclei):

in the process of irreversible elongation with some probability the system is clustered into two $^{82}_{32}Ge$, while the remaining nucleons, equivalent in number to $^{72}_{28}Ni$, form the neck coupling the clusters. If the clusterization hasn't occurred, the elongation continues and can be described by shell-model wave function. When the elongation is equal to the sum of $^{130}_{50}Sn$ and $^{80}_{32}Ge$ diameters, another clusterization may take place soon. At the bifurcation points with larger elongation, the $^{236}U^*$ nuclei can clusterize into $^{142}_{54}Xe$+$^{68}_{28}Ni$ and, apparently, another highly-coupled fragments (lines B,C,K, and B',C',K' of the shell corrections map /12/). If the system has clusterized into Sn+Ge, the nucleons which are equivalent to $^{24}_{10}Ne$ don't form such nuclei until the big clusters are at the necessary distance to make the "insertion" of the Ne cluster between them possible from the geometric and energy factors. Before this moment, these 10 protons with 14 neutrons appear to form a kind of plasma of light He clusters, nucleon pairs, etc. The composition of such plasma affects the odd-even effect in cold fragmentation yields. After condensation of neck nucleons into Ne nucleus, it is stretched by the rebelling big clusters until it decomposes into He clusters, alpha, tritons plus remainder, in analogy to Ikeda's rule. The fragmentation of Ne is the reason for the system scission in this fissile channel . The estimates in the "proximity" approach show that such discussed states are not forbidden energetically. The elongation values, calculated according to this scheme, for the bifurcation points to the "super-long" and "stI" valleys and for the scission points in the "stI" and "stII" valleys correlate with the calculations /13/ within 3-7%.

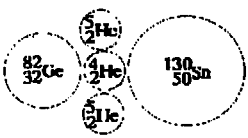

Fig.Possible scheme of fissile ^{236}U system.

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