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KINETIC ENERGIES OF FRAGMENTS IN NEUTRON - INDUCED NUCLEAR FISSION

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Abstract : The measurement results of the kinetic energy of fragments in neutron-induced nuclear fission are given in this paper. A relation of the detected peculiarities of the kinetic energy of fragments with vibrational resonances and shell effects is discussed here.

(fission, kinetic energy, neutron, shell structura, saddle point, scission point, thereshold)

The kinetic energy of fisssion fragments is made up from some parts the formation of which is determined at different stages of a nuclear fission process.

The main part of kinetic energy consists of the energy of Coulomb inter action of fragments at the moment of their formation. A high sensitivity to the configuration of fission fragments is characteristic of it. An influence of the shell structure of fragments upon kinetic energy has been discussed in detail in the work /1/. The results of numerous experiments are indicative of the maximum value of kinetic energy for pair fragments with $M_H \sim 132$ in a wide range of the A and Z fissile nuclei, this is being explained by a compact configuration of fragments close to a twice-shell fragment (N=82, Z=50). As excitation energy is increased the role of shell effects is decreased, that should be results in decreasing the kinetic

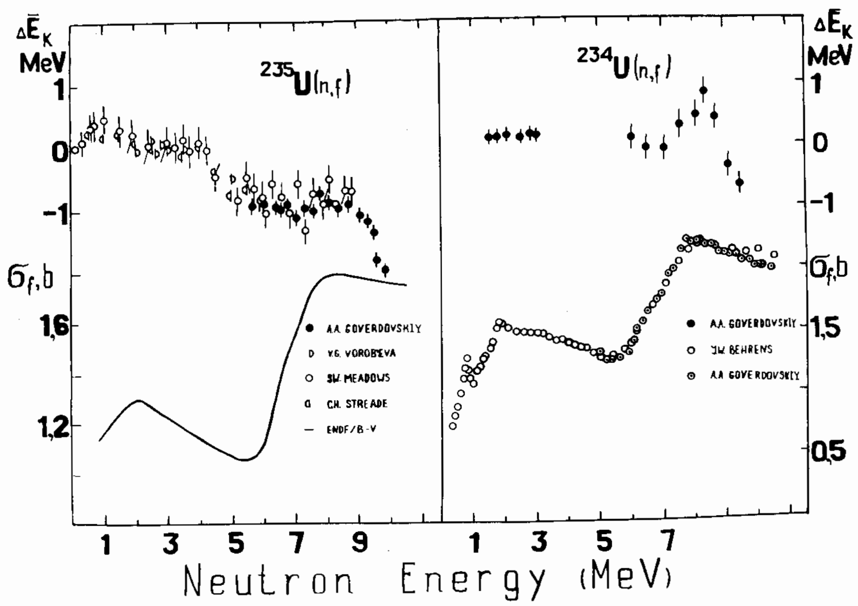

Fig.1 The ^{234}U, ^{235}U fission fragment kinetic energy

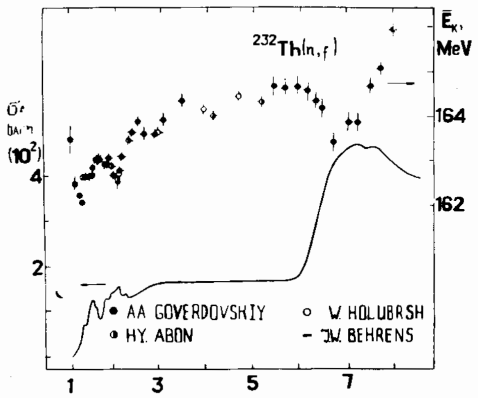

Fig.2 The ²³²Th Fission Fragment kinetic energy

energy of such fragments.

In the Fig.1 and Fig.2 are presented the dependences of average kinetic energies of fragments in neutron-induced fission of the ^{235}U, ^{234}U, ^{232}Th nuclei in the range of energies up to 10 MeV.

The kinetic energy at neutron-induced fission of ^{235}U has been studied in a number of the works /2-4/. In the Fig.1 is given the set experimental data.

These are agreed in the boundaries of measurement errors. The outlined decrease of $\bar{E}_k$ at $E_n \approx 4$ MeV is rapigly attenuated and the energy dependence of $\bar{E}_k$ forms a plateau up to $E_n \approx 8$ MeV with the subsequent sharp decrease of $\bar{E}_k$.

The slowing-down of decrease and the output of an energy dependence of $\bar{E}_k$ into a plateau can be explained by the contribution of fission events with the previous emission of neutrons, since in the neutron-induced fission of ^{234}U with the energy of up to 4 Mev, $\bar{E}_k \approx 172.2$ MeV and in the neutron-induced fission of ^{235}U with the energy of 6 MeV, $\bar{E}_k \approx 171$ MeV. However, a subsequent sharp decrease of $\bar{E}_k$ should be attributed to the $^{235}U(n,f)$ reaction, since for the $^{234}U(n,f)$ reaction in a suitable region of excitation energies $\bar{E}_k$ const. The decrease of $\bar{E}_k$ should account for about 2 MeV, when E_n is changed by 1 MeV.

The kinetic energy of fragments in the neutron-induced fission of ^{234}U has been studied in small detail. However, here, attention has been given to the resonancelike change of $\bar{E}_k$ at the outlet of a fission cross-section into the second plateau. In the process of ^{233}U fission in the region of neutron energies up to 4 MeV, $\bar{E}_k$ is practically constant, therefore, it has not been possible to explain the development of resonance by the contribution of fission events with previous emission of neutrons. If this resonance in an energy dependence of $\bar{E}_k$ will be attributed to the $^{234}U(n,f)$ reaction, then its amplitude should be accounted for about 2 MeV.

Attention is drawn to the fact, that on the average, the kinetic energy of fragments in nuclear fission of ^{232}Th, as E_n is increased up to 6 MeV, increases, moreover, the increase of $\bar{E}_k$ takes plase mainly at the expense of increasing the kinetic energy of pair fragments with $\bar{M}_H$ close to 150. The other mechanism of increasing $\bar{E}_k$ is connected with the decrease of $\bar{M}_H$, as the excitation energy is increased.

In the vicinity of the (n,n'f) reaction threshold and up to the outlet of a fission cross-section into the second plateau there is occured the decrease of $\bar{E}_k$, that is conditioned by a contribution of the fission events with the previous neutron emission.

An energy dependence of $\bar{E}_k$ in the ^{232}Th photofission is indicative of this fact.

However, in case of fission cross-section is going out into the second plateau the sharp increase of $\bar{E}_k$ is started. When neutron energies are increased by 1 MeV, the $\bar{E}_k$ increment is accounted for about 2 MeV. Such a behaviour can not be explained by a contribution of the fission events with the previous neutron emission, and if this increase is occured at the expense of the $^{232}Th(n,f)$ reaction, then the value of changins $\bar{E}_k$ should account for 4 MeV as E_n is increased by 1 MeV.

Thus, at the excitation energy of about 14 MeV there are occured the changes of $\bar{E}_k$ which are not got into the frames of a shell model /1/.

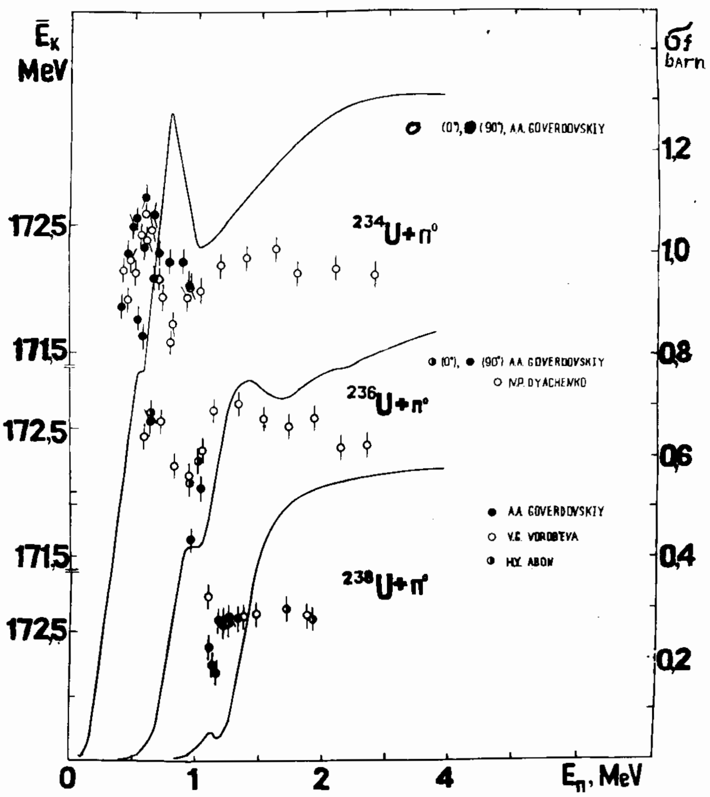

Fig.3. The fragment kinetic energy for nuclear fission near vibrational resonances.

The other kinetic energy component is connected with the potential energy released in the course of descending a nucleus from a saddle point to the scission point. Its quantity is measured by ten MeV and depended upon the fissioning nucleus and the force of dissipation processes at this stage of nucleas motion.

Unfortunately, at the present time the theoretical models which allow to make some realistic assessments of a contribution of this component into the kinetic energy of fragments in nuclear fission close to a barrier are not available.

The experimental data showing an influence of the stage of penetrating a potential fission barrier by a nucleus upon the kinetic energy of fragments have been obtained in the present work.

In the Fig.3 are given the mesurement results of the kinetic energy of fragments at the nuclear excitation energy close to a fission barrier.

The most remarkable effect is a systematic decrease of $\bar{E}_k$ in fission through vibrational resonances. For the greater realibility some condotions have been creat in the experiment, at which the contribution of fissions through vibrational resonance have been changed not only by change of neutron energy, but also by change of the angular distribution of registered fission fragments. The characteristic angular distribution of fragments is peculiar to nuclear fission through vibrational resonances. Thus, in the fission of ^{234}U by neutrons with an energy of E_n = 0.78 MeV the angular anizotropy of fragments accounts for β = 1.8 /5/, and at E_n = 0.55 β = 0.4 /5/.

The measurements of $\bar{E}_k$ in the fission of ^{234}U have been carried out in the two geometric conditions: in the first case there have been registered the fragments flying, for the most part, at 0°, and in the second case - at 90° relatively the direction of neutrons giving rise to nuclear fission. In the Fig.3 are shown the results of measurements.

It is seen, that the decrease of E_n is just occured in that case when there are evolved at most events corresponding to fission through vibrational resonance.

The simular measurements have been carried out for ^{236}U close to the neutron energy of 0.93 MeV. Once again $\bar{E}_k$ is decreased in fission through vibrational resonance (the Fig.3). Aso there been carried out the measurements of $\bar{E}_k$ in the neutron-induced fission of ^{238}U in the vicinity of vibrational resonance (E_n= 1.15 MeV). There are obtained here not very convincing results, since resonance is very weak and the width of resonance is not great. Nevertheless, the tendency for a decrease of $\bar{E}_k$ is seen in this case too (the Fig.3).

One more property of this phenomenon is that a decrease of $\bar{E}_k$ in the limits of measurement error does not depend on the method of dividing a nucleus into fragment masses.

This fact also confirms that the reason of $\bar{E}_k$ decreasing is connected with the stage of fission process when nuclear mass is not yet distributed between two fragments.

Thus, the decrease of kinetic energy of fragments has been observed for the three uranium isotopes in fission through vibrational resonances with different quantum characteristics.

The simular phenomenon takes place in the case of neutron-induced fission of ^{232}Th, too. However, here is still not attained a complete agreement of the experimental results obtained in different works.

In the work /6/ is available a possible interpretation of the mentioned effect based on considering the twodimensional potential surface. In this case vibrations in the second potential well are possible not only in the direction of fission but also to be perpendicular to it. In the latter case the vibrational energy is spent for gamma-quantum emission or dissipated into excitation energy. However, such a model leads to a global revision of the formed concepts of nuclear fissionability and requires a comprehensive experimental and theoretical study.

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