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STUDY OF DEEP SUBBARRIER REACTIONS ON A Pb TARGET

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The fission and evaporation cross section of a ^{224}Th compound nucleus has been measured in the reaction $^{16}O + ^{208}Pb$ up to 15 MeV below the fusion barrier, deeply in the subbarrier energy region, which made it possible to analyse cross sections by 8 orders of magnitude lower than the geometrical cross section of heavy ion interaction with nuclei.

The investigation has been performed at the Flerov Laboratory of Nuclear Reactions, JINR.

Изучение глубоконеупругих реакций на свинцовой мишени

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Сечения деления и испарительных реакций были измерены в реакции $^{16}O + ^{208}Pb$ в глубокоподбарьерной области энергий, вплоть до энергии 15 МэВ ниже барьера слияния ядер, что дало возможность для анализа сечений на 8 порядков величины меньше, чем геометрическое сечение взаимодействия ядер.

Работа выполнена в Лаборатории ядерных реакций им. Г.Н.Флерова ОИЯИ.

1. Introduction and Experiment

In the present work the fission and evaporation cross section of a ^{224}Th compound nucleus has been measured in the reaction $^{16}O + ^{208}Pb$ up to 15 MeV below the fusion barrier, deeply in the subbarrier energy region, which made it possible to analyse cross sections by 8 orders of magnitude lower than the geometrical cross section of heavy ion interaction with nuclei. The fission experiment has been carried out at the beam of the tandem accelerator (NFIN, Catania, Italy). Single fission fragments were detected in the backward angular range of 90-164° and 198-270° by using mica dielectric detectors with an area of 170 cm^2 [1]. Evaporation excitation functions have been measured for *xn*-, *pxn*-, and αxn-decay channels of the compound nuclei ^{224}Th produced at the beam of the U-400 cyclotron (FLNR, JINR, Dubna). Products of complete fusion reactions were separated from the bombarding ions and products of transfer and deep inelastic reactions with the aid of the kinematic separator VASSILISSA. Recoil nuclei and their α-decay were observed by means of a detector system installed in the separator focal plane. It consists of a pair of

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large-area time-of-flight detectors and a silicon detector array consisting of eight independent strips with the energy resolution of 30 keV for α-particles in the energy range of 5-9 MeV [2].

A great body of experimental data was recently obtained on subbarrier fusion cross sections, however, in all these investigations fusion-fission and fusion-evaporation cross sections are obtained within a wide high-energy range, while in the subbarrier region there are only several points, where the energy is below the barrier by 1-8 MeV. In addition, recently some works have been published, where the cross sections of evaporation reactions differ by one order of magnitude, see [3] and references therein. Our interest in the study of such deep subbarrier interaction is connected not only with a possibility of investigating the fusion cross section and discussing the mechanism of subbarrier reactions enhancement in the case of spherical nuclei interaction, but also with a possibility of investigating structural effects in different fission modes of compound nuclei, produced in reactions with heavy ions. Earlier this type of investigations has been carried out only in reactions with light charged particles [4].

2. Experimental Results and Discussion

The estimation of the fission and evaporation cross section necessarily involves both the details of the compound nucleus formation process and relative competition between fission and other modes in a ^{224}Th compound nucleus decay process.

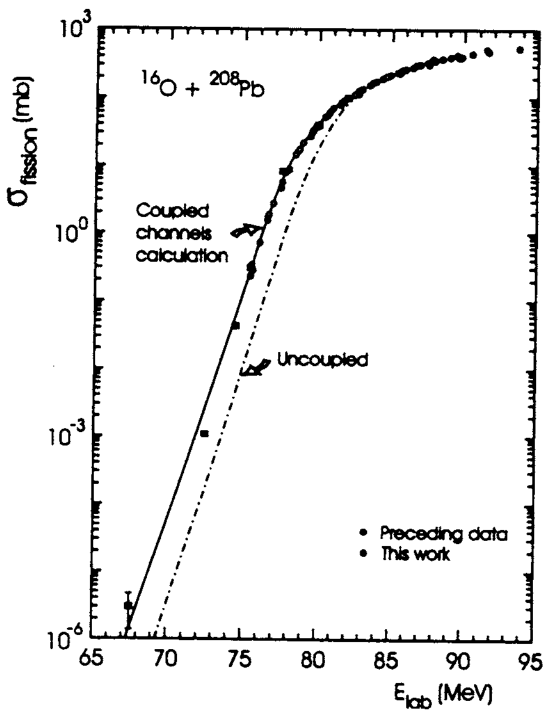

Fig.1

Calculations of the fusion cross sections were tested: (a) within the Wong approximation; (b) within the standard approximation of an inverted parabola with a nuclear potential in the form of Igo; (c) by the introduction of the vibrational zero-point motion of the surface; (d) by the method of coupled channels using a standard software package CCFUS. Figure 1 presents our experimental fission cross sections, data from different works joined in Ref.3 and results of calculations in coupled-channels approach. It is evident that at an ion energy of $^{16}O \leq 80$ MeV the subbarrier fusion cross sections, calculated using the Wong approximation or using the CCFUS software package disregarding the channel coupling, are going down much

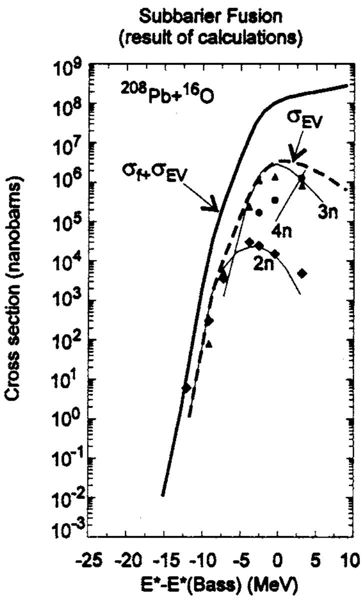

Fig.2.

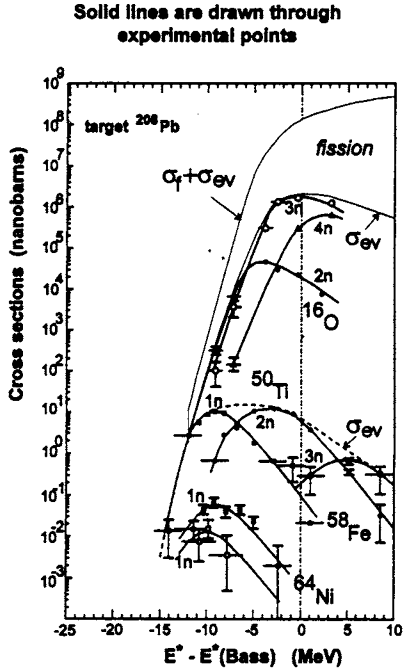

Fig.3

sharper and at an energy of $E^* = 72.5$ MeV are by nearly an order of magnitude lower than the experimental value of fusion cross section, whereas taking into account the channel coupling or zero-point vibrations leads to the increase of the cross section.

To analyse the fission and evaporation cross sections, we used a statistical model of the deexcitation process of compound nuclei which, for the sake of universality, uses the minimum number of physical assumptions and parameters [5]. It is shown that the evaporation reaction cross sections are well described in the framework of the statistical model taking into account shell effects according to Ignatyuk and it is also shown that such calculations, making use of only one set of model parameters, namely, the scaling factor to the liquid-drop barrier of Cohen, Plasil and Swiatecki $C = 0.65 \div 0.7$ and the ratio of the level density parameters $\hat{a}_f/\hat{a}_v = 1.0$, correctly describe the cross sections of evaporation reactions in a wide range of compound nuclei up to superheavy elements. In this work the dependence of the nuclear mass shell correction on the energy in the level density parameter and the fission barrier were introduced in calculations [6], $C = 0.67$, $B_f(l = 0) = 5.9$ MeV, respectively, and $l_{max} = 15$.

Figure 2 presents the comparison of the experimental data cross sections σ_{xn}, $\sigma_{ev} = \sigma_{xn} + \sigma_{pxn} + \sigma_{\alpha xn}$ and $\sigma_{ev} + \sigma_f$ with the results of calculations. The energy scale is presented as a difference between the excitation energy and Bass-barrier excitation energy $E^* - E^*$ (Bass). One can see from the figure that in spite of a wide range of cross sections variations, the calculations reproduce well enough both the relative and absolute values of the cross sections. In the interval of excitation energies of 20-30 MeV, the contributions of the two fission chances to the total cross section are approximately equal, which has to be taken into account in the analysis of different characteristics of the fission process. It should be noted that our experimental values of evaporation cross sections differ by an order of magnitude from the data obtained in [3], but agree with the results of earlier work [7].

And finally, the study of deep subbarrier reactions using a Pb target is of special interest, since they form the basis for the synthesis of superheavy elements in cold fusion reactions [8]. Figure 3 presents the experimental fusion cross sections with ions of ^{16}O and much heavier ions of ^{50}Ti, ^{58}Fe, and ^{64}Ni (solid lines are drawn through experimental points) [8], and one can see that for the nuclei under consirderation there are no substantial changes of the fusion reaction threshold, despite the substantial growth of the Coulomb forces (from ^{16}O to ^{64}Ni). This is a good reason to think that additional extra-extra push energy has not been observed.

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