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Direct neutron transfer in the ^{238}U(^{6}He, fission) reaction near the Coulomb barrier

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A recent measurement of direct α-particle emission from the ^{238}U(^{6}He, fission) reaction is shown to be strongly influenced by the fission trigger.

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Emission of α particles from the ^{6}He + ^{238}U reaction has recently been studied [1] in coincidence with a fission trigger. The cross sections deduced from this measurement are considerably smaller than those reported by Aguilera *et al.* [2,3] for the ^{6}He + ^{209}Bi reaction at a similar energy relative to the Coulomb barrier. An integrated yield of nearly 800 mb at a center-of-momentum (c.m.) ^{6}He energy of 21.8 MeV was measured with the ^{209}Bi target [2]. In the ^{238}U experiment, cross sections of about 100 mb at $E_{\mathrm{c.m.}} = 21$ MeV and 300 mb at $E_{\mathrm{c.m.}} = 29$ MeV were reported [1]. It will be shown that this discrepancy is likely not a target-dependent effect but instead results from the fission trigger used in Ref. [1].

Bychowski *et al.* [4] studied the one-neutron-transfer process ^{209}Bi(^{6}He,^{5}He)^{210}Bi at $E_{\mathrm{c.m.}} = 22.3$ MeV by detecting the neutron from the decay of ^{5}He in coincidence with an outgoing α particle. They found a one-neutron-transfer cross section of 155 ± 25 mb. Raabe *et al.* report no evidence for any one-neutron-transfer yield [1]. It appears from their Fig. 3 that the ^{239}U compound nucleus was assumed to be produced in states in the region of 10 MeV of excitation energy for fission to occur (though this value was not directly given in their article). However, the "Q-window" for $1n$ transfer is estimated to be at an excitation energy of about 4 MeV in ^{239}U and to have a width of about 5 MeV [5]. These values are consistent with the energy distribution of the α particles observed in Ref. [4]. As a result, very little α particle yield following $1n$ transfer is expected in coincidence with fission fragments.

A statistical-model calculation was carried out to estimate the fraction of the $1n$-transfer yield that might lead to fission. The code PACE2 [6] was used. The fission barrier for ^{239}U is 6.2 MeV [7], and the level-density parameters ($a = A/8$ and $a_f/a_n = 1.03$) were taken from Blann and Komoto [8]. The remaining input to the code is the angular momentum distribution in the compound system. A Poisson distribution with a mean of $1.5\hbar$ was assumed, since the cross section for populating these neutron-unbound states is expected to peak near zero angular momentum transfer because of the very long tail of the neutron wave function in this case. The results of this calculation are shown in Fig. 1. As expected, there is essentially no overlap of the excitation-energy distribution of the $1n$-transfer yield with the fission process. What is perhaps more surprising is that the fission probability is only about 5% even at an excitation energy of 10 MeV.

Because of the rather small fission probability computed above for ^{239}U, the decay of ^{240}U produced in the $2n$-transfer process was also calculated. In this case, the fission barrier is 5.6 MeV [7] and all the other parameters were taken to be those given above. The result is shown in Fig. 2. The fission probability varies from 25 to 50% over the range of excitation energies populated in this nucleus (10–20 MeV [1]).

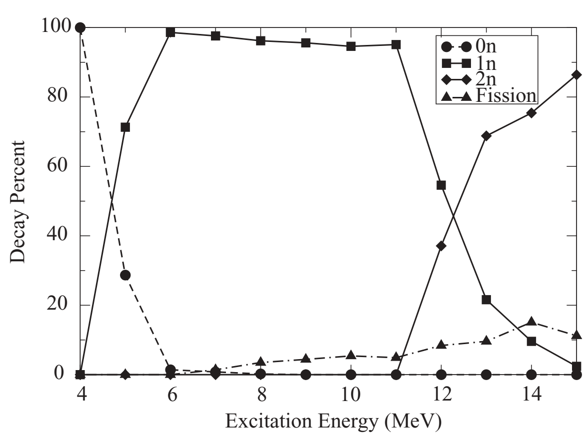

FIG. 1. The decay probabilities for states in ^{239}U populated via $1n$ transfer, as calculated using PACE2 with the parameters described in the text.

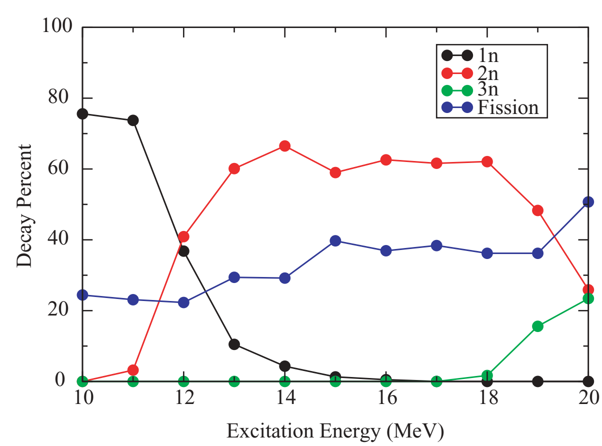

FIG. 2. (Color online) The decay probabilities for states in ^{240}U populated via $2n$ transfer, as calculated using PACE2 with the parameters described in the text.

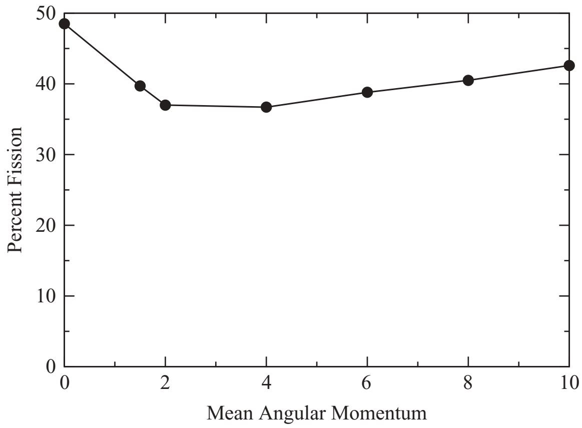

FIG. 3. The fission decay probability for states at 15 MeV of excitation in ^{240}U, as a function of the mean angular momentum of the distribution (units of $\hbar$).

Its mean value is about 35%. To check the angular momentum dependence of this result, Gaussian distributions having a full width at half maximum of $1\hbar$ and mean values ranging from 2 to $10\hbar$, as well as a δ function at zero angular momentum, were also tried. The excitation energy in the compound nucleus was taken to be 15 MeV. The results of this series of calculations, shown in Fig. 3, suggest that the total $2n$-transfer yield is about 2–3 times that reported in Ref. [1].

In conclusion it should be noted that the results given here do not affect the transfer-fission yields reported in Ref. [1]. However, the total direct-transfer cross sections are expected to be much greater, in better agreement with those reported in Refs. [2,3], because of the inefficiency of the fission trigger.

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