On a possible method for identifying fission isomers with lifetimes ~ psec - nsec

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Introduction

Fission isomers were first discovered by Polikanov [1]. Subsequently these were understood to arise from the existence of a second minimum in the deformation dependent potential energy of heavy nuclei. Nuclei populated in a second potential energy minimum would be expected to have fission lifetimes much shorter than that of the ground state but much longer than typical compound nuclear decay times. Such isomers have been identified in the actinide region with lifetimes (τ_{fiss}) ranging from msec – 10 psec [2]. As can be seen from Table 1, which lists the techniques used for fission lifetime measurements, there is window in the range of 10^{-11} sec to 10^{-16} sec which has not been accessed hitherto. A part of this region could be accessed using a technique which is proposed for the first time, as far as we know, in this contribution. Such isomers may be of interest in determining the onset of super-heavy element island of stability in the (N,Z) nuclide chart.

Table 1. Fission lifetime measurement techniques

Method	τ_{fiss} (sec)
Neutron clock	10^{-20}
Crystal channeling/ blocking	10^{-16} - 10^{-17}
K-Xay	10^{-17}
Electronic timing	$> 5\times 10^{-10}$
Recoil distance	$> 10^{-11}$

The method

Heavy ion (HI) fusion reactions are often used to populate heavy compound nuclei. If the fissioning compound nucleus (CN) recoils in a stopping medium its velocity decreases as it penetrates deeper in the medium. The velocity of a recoiling CN leads to an angle dependent velocity boost to the fission fragments (FF) in the laboratory. The folding angle, θ_{FF}, between the fission fragments is thus less than 180° for in-flight fission decay. However if the nucleus stops before undergoing fission decay θ_{FF} will be 180°. In other words, a short lifetime on the scale of the stopping time leads to $\theta_{FF} < 180°$ and is decided by the decaying nucleus velocity folded with the fragment velocities while a long lifetime results in a back to back fission fragment emission with $\theta_{FF} = 180°$.

The other observable is the kinetic energy of the fission fragments. The kinetic energy of each fragment is decided by the FF kinetic energy in the frame of the fissioning nucleus, its velocity and the emission angle of the FF in the lab (or alternatively in the centre of mass). If a thin target is backed by a stopping material, the observed kinetic energy (KE) of the FFs depends on whether the CN fissions before or after stopping. Different backing materials, with different stopping powers, could be used to confirm a lifetime measured using this method, were an isomer with a suitable lifetime to be found.

It may be mentioned that a fission isomer in this lifetime range is likely to be only weakly populated with a branching fraction $\sim 10^{-6}$. Hence any sizable tails in the folding angle distributions could cause problems in the measurement.

Another potential difficulty with the measurement is the intrinsic spread in the kinetic energy (KE) distribution for a given mass split. This is, for example, about 12 MeV (σ_E ~ 5 MeV) [3] for the light fragment in ^{236}U fission induced by thermal neutrons. For a typical KE of about 100 MeV this 12% spread is less than, or comparable to, the boost in energy due to the recoil of the fissioning compound nucleus. For example, let us consider a 200 MeV beam of ^{32}S bombarding a ^{209}Bi target. The CN recoil velocity β (=v_{CN}/c) is ~1.54% while that of the fission fragment, for an equal mass split using the Viola systematics [4], is ~4.17%. Fig.1 shows the results of a Monte Carlo simulation for the two limiting cases and includes the KE distribution of the FFs. For reference, the stopping time of the above CN in aluminium is ~2.5 psec. The mass distribution and the effect of angular straggling in the target and backing material have not yet been included and work on both these aspects is in progress. This will also address the detection limits on the branching fractions of such fission isomers.

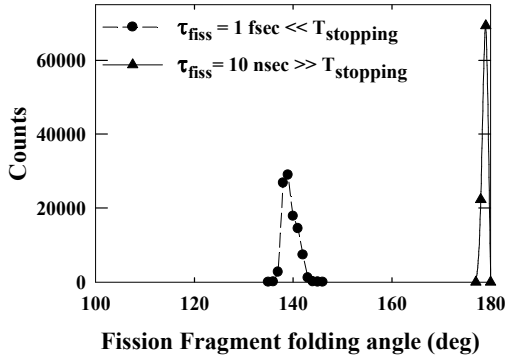

Fig. 1. Fission fragment folding angle distribution for above example.

It may be pointed out, however, that the kinetic energies of the fission fragments could be measured to reduce the folding angle spread for a certain cut in the KE distribution. There is then a correspondence between a folding angle and the decay time leading to the possibility of measuring simultaneously lifetimes of more than one isomer.

Examples of possible systems for study

What might be the best system to study or for making a feasibility run? The first criterion is the recoil velocity needs to be ~20% or larger that of the fission fragments to cause (a) a sizable decrease in the fission fragment folding angle in comparison with 180°, (b) a measurable shift between the FF kinetic energies from a moving CN and those from stopped CN decay and (c) a reasonably high fission barrier and as low an excitation energy as possible. Some examples using HI ion fusion reactions are listed in Table 2. The fission barrier (B_{fiss}) is taken from Ref. [5].

Table 2. Possible test systems

System	CN	V_{CB} (Lab) (MeV)	E_X^{CN} (MeV) #	B_{fiss} (MeV)
^{32}S+^{209}Bi	^{241}Es	172.9	41.7	3.59
^{36}S+^{209}Bi	^{245}Es	173.4	32.6	5.70
^{16}O+^{208}Pb	^{224}Th	86.06	33.4	8.27

for E_{beam}=V_{CB}(Lab)

It might also be possible to use the recoil from sub-Coulomb (for example, one and two neutron) transfer induced fission on heavy targets to populate fission isomers. This has the advantage of peaking at backward angle leading to a large recoil corresponding to ~ twice the beam momentum. Work is in progress to measure the fragment-fragment angular correlation for a known fission isomer to experimentally determine the detection limits of fission isomers of different lifetimes by this method.

References

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