A method to estimate transmission efficiency of HYRA

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The HYbrid Recoil mass Analyzer (HYRA) [1] is a dual mode, dual stage recoil separator for heavy ion-induced reaction mechanism studies at IUAC. The first stage of the HYRA is designed to operate with dilute helium gas in the magnetic field region and thus called a gas-filled separator [2]. This class of recoil separators are extensively used to measure evaporation residue (ER) formation cross section ($\sigma_{\rm ER}$) in complete fusion reactions. Experimentally, $\sigma_{\rm ER}$ is determined by the relation

$$\sigma_{\rm ER} = \frac{Y_{\rm ER}}{Y_{\rm norm}} \left(\frac{d\sigma}{d\Omega}\right)_{\rm Ruth} \Omega_{\rm norm} \frac{1}{\epsilon} \qquad (1)$$

where $Y_{\rm ER}$ is the ER yield at the focal plane of the separator, $Y_{\rm norm}$ is the yield at the normalization detector, $\left(\frac{d\sigma}{d\Omega}\right)_{\rm Ruth}$ is the differential Rutherford scattering cross section in the laboratory system, $\Omega_{\rm norm}$ is the solid angle subtended by the normalization detector. ϵ is the transmission (or transport) efficiency of the separator, which is defined as the ratio of the number of ERs reaching the focal plane to the total number of ERs produced at the target chamber. ϵ contributes the maximum to the overall error in $\sigma_{\rm ER}$ and is a complex function of several parameters [3].

ERs emerge from the target with broad distributions in angle, energy and charge state. Only small fractions of these distributions lie within the respective acceptances of the separator. The distributions can be generated quite *realistically* using Monte Carlo techniques and ER trajectories can be simulated, provided energy and charge state are not altered inflight, employing standard ion optical methods. One can thus calculate ER transmission efficiency in vacuum mode recoil separators *e.g.* the Heavy Ion Reaction Analyzer (HIRA) [4].

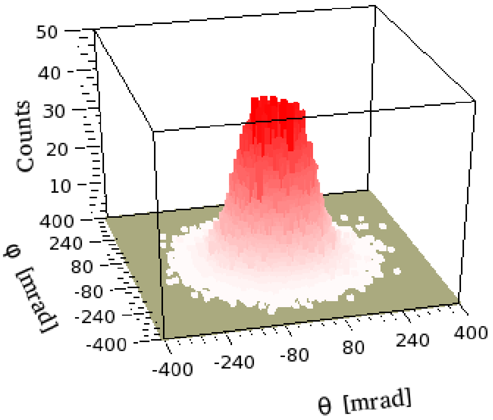

FIG. 1: Simulated ER angular distribution for the reaction (96.0 MeV) ^{16}O+^{184}W (210 μg/cm^2) $\rightarrow$ ^{195}Pb+5n. Calculation was performed for 10^6 events. θ and ϕ are divergence in the dispersive (horizontal) and non-dispersive (vertical) planes, respectively.

In a gas-filled separator, ERs undergo numerous collisions with the gas molecules along their paths towards the focal plane detector thereby changing their energy and charge state. Mathematical modelling of these processes is far more complex and demands much longer computational time, compared to simulating ER trajectories in a vacuum mode recoil separator.

However, it has been reported [5, 6] that charge state and energy acceptances of gas-filled separators are nearly 100% due to inherent charge state and velocity focusing. Thus the angular distribution of the ERs and the angular acceptance of the separator set the upper limit of transmission efficiency in a gas-filled separator.

We utilised this observation to estimate

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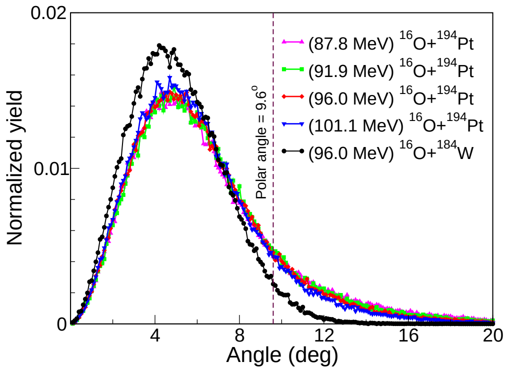

FIG. 2: Normalized ER angular distributions for the reactions ^{16}O+^{184}W and ^{16}O+^{194}Pt, simulated by TERS. The vertical line at 9.6° indicates angular acceptance of the HYRA. It may be noticed that ER angular distributions for ^{16}O+^{194}Pt at different beam energies are quite similar, but differ significantly from the more symmetric reaction.

ER transmission efficiency for the reaction ^{16}O+^{194}Pt in HYRA by comparing total ER angular distribution of this reaction with the same of a known reaction [7]. ^{16}O+^{184}W reaction was used as the reference, for which ER excitation function had been reported earlier [8, 9]. The same reaction was studied again in HYRA at 96 MeV beam energy and ϵ was calculated using Eqn. 1. We obtained ϵ = 2.48 ± 0.40% and 1.78 ± 0.27% with a 57×57 mm^2 multi-wire proportional counter and a 50×50 mm^2 position-sensitive silicon detector at the focal plane, respectively.

Next we calculated ER angular distributions for individual exit channels for the two reactions by the semimicroscopic Monte Carlo code TERS [10]. A three-dimensional view of simulated ER angular distribution for a specific exit channel of ^{16}O+^{184}W is shown in Fig. 1. To obtain total ER angular distribution for the two systems, as total σ_{ER} was measured in HYRA, angular distributions of individual exit channels were combined with proper weightage calculated by PACE3 [11]. Total ER angular distributions for the two reactions at different beam energies are shown in Fig. 2. Counts were compared within a polar acceptance angle of 9.6°, corresponding to entrance aperture of the first quadrupole magnet of the HYRA. For the purpose of comparison, total number of ERs (in other words, area under the curve) was kept the same in all cases. At 96 MeV beam energy, area under the total angular distribution curve for ^{16}O+^{194}Pt reaction was approximately 10% less than that for ^{16}O+^{184}W reaction, within the angular acceptance. This reduction in area was expected for ^{16}O+^{194}Pt because of its more asymmetric entrance channel compared to the latter reaction. Hence, at 96.0 MeV transmission efficiency of HYRA for ^{16}O+^{194}Pt was determined to be 1.60 ± 0.24% (with the silicon detector), using a scaling factor 0.9. Scaling factors for other energies were also deduced in a similar fashion, details of which can be found in [7].

Encouraged by the present result, we are exploring application of the scaling method to other gas-filled separators, which is reported elsewhere [12].

References

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