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A Monte Carlo code to calculate transmission efficiency of HIRA

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Abstract

A semimicroscopic Monte Carlo code is presented for calculating absolute transmission efficiency of the Heavy Ion Reaction Analyzer at IUAC. The code generates realistic distributions for energy, charge state and angle of evaporation residues (ERs) produced in heavy ion-induced complete fusion reactions. Further, individual ER trajectories are calculated using first-order transfer matrices. Trajectories in dispersive and non-dispersive planes and one as well as two-dimensional position spectra of the ERs at the focal plane are simulated by the code. Calculated efficiencies are in good agreement with measurements.

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Keywords: Monte Carlo simulation; Recoil separator; Heavy ion fusion; Ion optics; Transmission efficiency

1. Introduction

The Heavy Ion Reaction Analyzer (HIRA) [1] at IUAC is one of the early recoil mass spectrometers based on symmetric ED–MD–ED configuration, pioneered in Rochester [2], where ED and MD stand for electrostatic dipole and magnetic dipole, respectively. Two quadrupole doublets, viz Q1–Q2 and Q3–Q4 are used before and after the dipoles. Electromagnetic configuration of HIRA is schematically shown in Fig. 1. Triple focus conditions $[(x,\theta) = (y,\phi) = (x,\delta(E/q)) = 0]$ are obtained at the focal plane with a non-zero mass dispersion $[(x,\delta(A/q)) \neq 0]$. Here E, A and q stand for energy, mass and charge state of the ions, respectively, and the coordinates x,θ,y,ϕ are explained in Fig. 2.

In case of heavy ion-induced complete fusion reactions in normal kinematics, HIRA rejects primary beam particles and multinucleon transfer reaction products, transports the evaporation residues (ERs) to the focal plane and disperses them according to their A/q values.

Transmission efficiency of HIRA is an important quantity for measurement of absolute reaction cross-sections. Knowledge of transmission efficiency for the chosen reaction channel beforehand, also helps in proper planning and execution of the experiment.

Transmission efficiency for a system can be measured by γ-ray method [3] in which γ-rays from the ERs are measured in singles and in coincidence with the ERs, detected at the focal plane of the separator. The ratio of counts of a specific γ-line, corresponding to a particular ER, in coincidence spectrum to that in the singles spectrum gives the absolute transmission efficiency of the separator. This method, though simple and direct, is limited by the requirement of good statistics in each γ-line and therefore is successful only for abundant channels.

One can also determine transmission efficiency of a separator by simultaneous measurements of elastically back-scattered beam particles and the corresponding forward-moving target-like recoils [4]. Such measurements are carried out at energies significantly lower than the Coulomb barrier to ensure validity of Rutherford scattering.

However, experimental determination of transmission efficiency at every energy step during excitation function measurement or for different exit channels of a reaction is not practicable. For very weak channels also, one needs to depend on a reliable theoretical estimate of transmission efficiency. Standard ion optical optimization codes (e.g. GIOS [5]) take average values of ER parameters as inputs,

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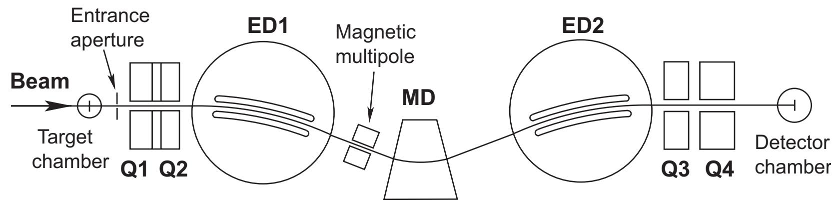

Fig. 1. Schematic of the electromagnetic configuration of HIRA.

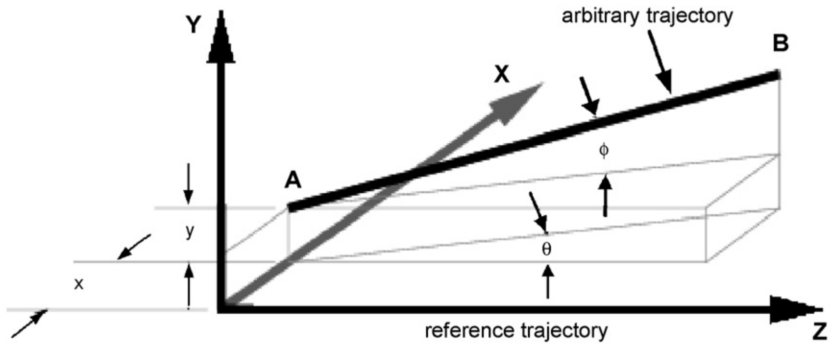

Fig. 2. A section of an arbitrary trajectory (from A to B) in drift space. Deviations from the reference trajectory (z-axis) are shown. The coordinates x, θ, y, ϕ are used for trajectory calculation using first-order transfer matrices [17,18].

hence the transmission efficiency calculated by them is only approximate. Alternately, one can calculate ER angular and energy distributions using a standard statistical model code (e.g. PACE [6]) and charge state distribution using formulae available in literature. These distributions may then be folded with the corresponding acceptances of the separator to estimate transmission efficiency.

In this paper we report a semimicroscopic Monte Carlo code for calculating absolute transmission efficiency of HIRA for ERs produced in heavy ion-induced complete fusion reactions. Similar semimicroscopic calculations had been reported earlier for other separators [7–9]. Our code is a significant improvement over those, especially in the treatment of particle evaporations from compound nucleus (CN), where individual particle separation energies are included in the calculation. Several other new features, e.g. trajectory plots, one and two-dimensional position spectra and quantitative information on survival of ERs at different locations of HIRA are also offered by this code. The details are described in Section 2. Results and discussions are presented in Section 3, followed by a summary in Section 4.

2. Description of the code

The code is written in C and structured as described below.

2.1. User inputs

The code requires the following as user inputs for calculation of transmission efficiency:

(i) atomic number and mass number of projectile and target,
(ii) beam energy and target thickness,
(iii) beam-spot size,
(iv) Q-value for CN formation,
(v) inverse level density parameter,
(vi) numbers of evaporated α, proton and neutron,
(vii) particle separation energies,
(viii) HIRA settings (i.e. reference particle parameters and entrance aperture),
(ix) dimensions of focal plane detector, and
(x) number of events (ERs).

2.2. Calculation of ER parameters

Based on user inputs, the code *produces* ERs by the interaction of beam particles with target nuclei. For each ER, six ion optical parameters are calculated (x, θ, y, ϕ, E and q). The method followed for calculating these parameters for a single ER is described below.

The beam particle after entering the target loses energy, fuses with a target nucleus and forms the CN. We assume that fusion cross-section remains constant over the thickness of the target and therefore fusion may occur anywhere within the target. This simplified assumption will not be valid in case of thick targets and when beam energy is around the Coulomb barrier for a given reaction. In those cases, one requires the knowledge of excitation function a priori and the *fusion-point* can be chosen accordingly. Energy loss of the beam particle upto the point where fusion occurs is calculated [10] and the CN is formed with residual beam energy. Kinetic energy and excitation energy