In-Flight Separation of Superheavy Nuclei: Conceptual Study of a Next Generation Experiment

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Introduction

Superheavy element research has shown impressive results. The synthesis of Copernicium, element 112 [1], has been accepted by IUPAC and new elements up to Z=118 have been reported [2]. Experiments on the spectroscopy of transactinide elements have been done and elements as heavy as lawrencium, element 103, have been measured successfully in an ion trap. These experiments are, however, at the very limit of present experimental capabilities in terms of production cross sections and methods for identification [3]. The heavy nuclei were produced by cold fusion with ^{208}Pb or ^{209}Bi targets and appropriate heavy ion beams or by hot fusion with ^{48}Ca beams combined with actinide targets. All new elements are separated in-flight and identified by characteristic decay patterns of individual nuclei.

Despite being at the very limit of detection sensitivity, progress is being made in experimental techniques. The considerable experience gained in the process will be put to test in facing new challenges in the development of advanced detection techniques required to approach the region of superheavy nuclei near N=184 and to synthesize elements beyond Z=118. The focus and primary aim of this study presently underway, is to address these questions. The new challenges may be itemized as follows:

- development of superconducting high current accelerators such as the LINAG (GANIL) providing beam intensities of the order of 10^{14} particles/s - a factor 50 above the intensities used presently
- investigation of new synthesis reactions such as nucleon transfer reactions,
- direct determination of the mass number.

As a first step we present possible separator schemes based on the knowledge collected in performing first-generation experiments.

Separators applied in SHE Research

In-flight separators used in SHE research [3,4] are SHIP (GSI) - a velocity filter, and the gas filled separators DGFRS (JINR Dubna), GARIS (RIKEN), and TASCA (GSI). The electrostatic filter, VASILISSA (JINR Dubna), FMA (Argonne), a recoil product mass analyzer, and the gas filled separators BGS (LBL Berkeley) and RITU (JYFL) have also been used to create and study the trans-uranium elements.

These systems can be classified either as kinematic separators, sensitive to reaction kinematics, or separators with mass or charge separation.

Some General Considerations

Kinematic separators have low resolution when accepting all reaction products emitted into a large phase space. They work as filters. SHIP for example has a velocity resolution of about 100. Recoil product mass separators separate in mass over ionic charge state, A/Q. The multiple ionic charge distribution of swift ions emerging from a target creates a number of lines for each nuclide. Therefore the A/Q resolution should be in excess of 600 to create usable spectra. Gas filled separators are sensitive to $A/Z^{1/3}$ with poor resolution but sufficient to separate superheavy nuclei from the projectile beam.

A separator to be used at high-current accelerators must work at high beam intensity and have high background suppression. The background suppression is achieved in a two-step device with each step having different separation criteria. A vacuum separator should be as short as possible to avoid losses of very short lived species as expected beyond Z=118 and isomers which convert in-flight and are lost because of Auger cascades.

Limitations

In-flight separators separate reaction products as they emerge from the reaction target. Their phase space is generally large and determined by the emittance of the projectile beam, reaction kinematics, and interactions in the target. To achieve high resolution large beam emittance requires large-area dispersive magnetic and electrostatic fields. For reaction products emitted from a beam spot at the target of the width $2x$ into an angle $2x'$ the field area S necessary to achieve the resolution R is: $S = R\,2x\,2x'\rho$ where ρ is the deflection radius of the beam in the field. Moreover the multiple ionic charge states and the energy spread of the ion beam require large field areas in case of large dispersion. Therefore a mass resolution of 600 is difficult to realize for a recoil separator of high transmission. Tracking may help but is not efficient for slow and heavy recoils such as superheavy nuclei produced in hot or cold fusion near Coulomb-barrier.

An elegant way out of this problem is a beam stopper and cooler combined to a high resolving Time-Of-Flight (TOF) mass spectrometer, the high repetition rates allow for high background rates from transfers or fission products. A detector system at the exit of the TOF allows a complete measurement of the decay characteristics of the mass resolved nuclei. This technique allows identifying the nuclide produced even if the top of the chain is lost because of very short decay half-lives. Another solution would be to use bolometric detectors.

An illustrative Example

Based on these considerations we provide a schematic representation of a possible next generation in-flight separator in Fig. 1. The first stage is a velocity filter to dump the projectile beam and to transmit only products from complete fusion and with high efficiency. The second stage is a dipole magnet with moderate resolution to suppress scattered ions, mainly projectiles, without splitting the ionic charge distribution too much. Detection and mass identification are achieved by bolometric detectors or an ion catcher-cooler combined with a TOF and a detector. While such a scheme (Fig. 1) involving an ion trap works at SHIP, it will need to be much improved and modernized.

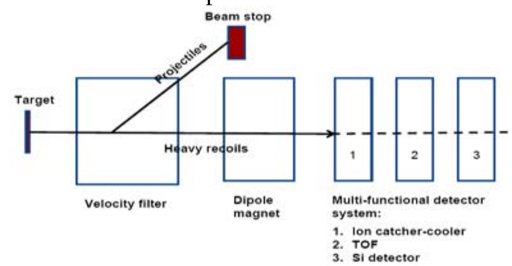

Figure 1: In-flight separator for fusion products

A new idea gaining currency is to search for super heavy nuclei produced in transfer reactions at picobarn sensitivity levels with in-flight separation. The problem is to collect the reaction products emitted into a broad angular range with high efficiency. Under discussion is the possibility of using a superconducting solenoid to collect the reaction products with high efficiency. Among other options we are also exploring a possible scheme which is more sensitive to reaction kinematics by adding an RF condenser for additional cleanup by a TOF separation. The projectile beam is dumped in a catcher positioned inside the solenoid. Again identification is achieved with an ion catcher-cooler-TOF system or bolometer. Both concepts are being explored in further detail and investigations are in progress.

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