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Nuclear Instruments and Methods in Physics Research A 544 (2005) 565–576

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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EMMA: A recoil mass spectrometer for ISAC-II at TRIUMF

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Received 13 September 2004; received in revised form 5 January 2005; accepted 7 January 2005
Available online 11 March 2005

Abstract

Design work has begun on EMMA, an electromagnetic mass analyzer for ISAC-II at TRIUMF. EMMA is a recoil mass spectrometer that will be used to separate the recoils of nuclear reactions from the beam, and to disperse them according to mass/charge. ISAC-II will provide intense, low-emittance beams of unstable nuclei with masses up to 150 u and maximum energies of at least 6.5 MeV/nucleon. EMMA will be used in many different types of experiments with radioactive beams, especially those involving fusion-evaporation and transfer reactions. As such, it must be both efficient and selective, possessing large acceptances in angle, mass, and energy without sacrificing the necessary beam suppression and mass resolution.

PACS: 07.75.th; 25.60.−t; 29.30.Aj

Keywords: Recoil mass spectrometer; Electromagnetic separator; Recoil separator

1. Introduction

An electromagnetic mass analyzer, EMMA, is planned for use with the heavy radioactive ion beams that will be available from the ISAC-II facility at TRIUMF. ISAC-II will provide intense, high-quality beams of radioactive ions with masses up to 150 u and maximum energies of at least 6.5 MeV/nucleon [1]. These beams will allow the study of the single-particle structure of exotic nuclei, the evolution of nuclear structure and shapes far from stability and at high spin, fundamental symmetries, and nuclear astrophysics. Some of the techniques needed to explore these subjects include Coulomb excitation, fusion evaporation, and transfer reactions initiated by heavy radioactive ions in inverse kinematics. The study of many of these reactions will require detection and identification of the heavy recoil nucleus, in addition to light charged particles, neutrons, and γ rays. The former will be the purpose of EMMA, a recoil mass spectrometer designed to separate the recoils of a nuclear

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0168-9002/$ - see front matter
doi:10.1016/j.nima.2005.01.297

reaction from the primary beam, and to disperse them in a focal plane according to their mass-to-charge ratio (M/q).

In the recent past, several different types of ion-optical configurations have been employed to fulfill roles similar to that envisioned for EMMA at ISAC-II. The first is a velocity filter that uses a Wien filter or separated electric dipole (ED) and magnetic dipole (MD) fields to disperse beam and recoils according to velocity. An example of this type of recoil separator is SHIP at GSI [2]. A second type is a gas-filled recoil separator, which relies on collisions of heavy ions with a dilute gas filling a magnetic spectrometer to separate beam and recoils. RITU in Jyväskylä [3] is such a separator. Thirdly, there are large acceptance magnetic spectrometers such as PRISMA at INFN Legnaro [4] and MAGNEX at LNS Catania [5]. In addition, there is the hybrid spectrometer VAMOS at GANIL [6], which incorporates a Wien filter in a magnetic spectrometer. Finally there are vacuum-mode recoil mass spectrometers based on EDs and MDs which disperse according to M/q instead of velocity. The first such device was built at the University of Rochester [7,8], and several similar spectrometers have been constructed around the world. A recent review of gas-filled separators can be found in Ref. [9], and vacuum-mode separators are reviewed briefly in Ref. [10].

2. Scientific program

EMMA will be an integral part of the experimental program at ISAC-II, both as a stand-alone device and in conjunction with other detection systems. One important avenue of research will involve the coupling of EMMA with the advanced γ ray detector array TIGRESS [11]. By positioning TIGRESS around the target position of EMMA, prompt γ rays emitted by a recoiling nucleus formed in a fusion-evaporation or transfer reaction can be correlated with the arrival of the recoil at the focal plane of EMMA. Focal plane detectors will allow the determination of the mass and in many cases the atomic number of the recoil using position, energy loss, and time-of-flight measurements. The recoil information allows very weak reaction channels to be studied in the presence of very high yield background channels, enabling the exploration of high spin states in exotic nuclei as well as their low-lying, single-particle structures.

By implanting the recoils in a double-sided silicon strip detector (DSSD), the full power of the recoil decay tagging technique can be employed. In this method, the observation of prompt γ rays near the target is combined with the detection of charged particles such as α particles, protons, and β-delayed protons emitted in the radioactive decay of mass-identified recoils implanted in a silicon detector behind the focal plane. Since typical flight times through EMMA will be $\lesssim 1\,\mu s$, short half-life radioactivities can be studied. Placing γ detectors at the focal plane will allow the study of μs isomers. Replacing the DSSD with a thin catcher foil and positioning silicon PIN diode detectors behind it will permit the detection of conversion electrons emitted in the decay of implanted recoils.

In transfer reactions, the detection of the light ejectile is essential for the measurement of the recoil excitation energy. For this purpose, a silicon strip detector array (e.g., Ref. [12]) would be positioned around the target position and operated in coincidence with the focal plane detectors of EMMA. These reactions can be used to measure the excitation energies, spins, and parities of low-lying levels in the recoil nucleus. Such studies are essential for elucidating the changes in nuclear structure away from stability, and for the determination of the properties of resonances important in nuclear astrophysics.

3. Implications of scientific aims for spectrometer design

Two types of reactions will place the most stringent demands on EMMA, fusion-evaporation and single-nucleon transfer in inverse kinematics. Though they are centred about 0°, the products of fusion-evaporation reactions emerge from the target with a relatively large spread in angle and energy. This spread depends on the reaction kinematics, including the ratio of beam and target