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A new device for combined Coulomb excitation and isomeric conversion electron spectroscopy with fast fragmentation beams

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Abstract

A new setup has been designed to perform Coulomb excitation experiments with fragmentation beams at intermediate energy and to measure at the same time conversion electrons from isomeric states populated in the fragmentation reaction. The newly designed setup is described and experimental results from a first experiment are shown. Radioactive even–even nuclei in the mass region $A \simeq 70$ close to the $N = Z$ line were Coulomb excited after fragmentation of an intense primary ^{78}Kr beam and selection in flight with the LISE3 spectrometer at GANIL. The γ rays emitted after Coulomb excitation were detected in an array of four large segmented HPGe clover detectors in a very close geometry. The scattered ions were identified in a stack of highly segmented annular silicon detectors combined with a time-of-flight measurement using beam tracking detectors. Conversion electrons from isomeric 0^+_2 states decaying via electric monopole transitions were detected in an array of segmented cooled silicon detectors surrounding a telescope of plastic scintillators. Reduced transitions probabilities $B(E2; 0^+_1 \rightarrow 2^+_1)$ were deduced for several stable and radioactive nuclei.

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1. Introduction

A new device is presented for the combined spectroscopy of prompt γ rays and isomeric conversion electrons after reactions using fast beams from a fragmentation facility. It has been developed for the physics case of nuclei in the mass region $A \simeq 70$ close to the $N = Z$ line, where low-lying 0^+ states related to shape coexistence and shape isomerism are very common. Such low-lying 0^+ states have been observed experimentally in the even–even Ge isotopes from $A = 68$ to 78, in the Se isotopes from mass $A = 70$ to 82, and in the Kr isotopes from mass $A = 72$ to 84 [1].

The $N = Z$ nuclei ^{68}Se and ^{72}Kr are also of major importance for the rapid proton capture (rp) nucleosynthesis process on the neutron-deficient side of the nuclear

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chart [2]. Both nuclei are thought to be waiting points in the rp process: the synthesis of heavier elements can only proceed after β decay of rather long-lived isotopes or the sequential capture of two protons. Nuclear structure information of low-lying isomeric states is also an important input parameter for simulations of the rp process [3].

Nuclei in the middle of the *fp* shell have a large quadrupole deformation in their ground state, and adding or removing a few nucleons can change the nuclear shape dramatically. The self-conjugate nucleus ^{72}Kr is predicted to have an oblate deformation in its ground state [4–7], while the heavier Kr isotopes were shown to have prolate ground-state deformation and excited states with oblate shape [8]. The first experimental evidence for this shape coexistence was the observation of low-lying 0_2^+ states [9]. A similar scenario is expected for the light Se isotopes. However, the situation is less clear experimentally, since no low-lying 0_2^+ state has been observed in ^{68}Se.

If a low-lying 0^+ state in ^{68}Se is located below or just above the first 2^+ state, its decay occurs (exclusively or predominantly) via an $E0$ transition, i.e. through the emission of a conversion electron. The excited 0^+ state then becomes meta-stable with a lifetime of the order of a few to several hundred nanoseconds, depending on the overlap of the wave functions of the two 0^+ states. If the nuclei are produced in a high-energy fragmentation reaction ($E > 40$ A MeV), they have a high probability of being fully stripped of their atomic electrons (see discussion in Section 2). In this case the $E0$ decay is blocked (if the excitation energy of the excited 0^+ state is insufficient for internal pair creation), and the decay can only proceed once the nuclei have regained their atomic (inner-shell) electrons, e.g. after passage through thick materials or after implantation into a detector.

Intermediate-energy Coulomb excitation after fragmentation is a well-known technique used to measure the reduced transition probability $B(E2; 0_1^+ \rightarrow 2_1^+)$ for exotic nuclei far from stability, which gives a first indication on the collectivity of the nucleus [10]. Specific equipment has been designed at GSI [11], RIKEN [12], MSU [10], and previously at GANIL [13] for such measurements. Taking advantage of the high beam energy, thick targets can be used to increase the interaction probability. Coulomb excitation events can be separated from other reaction mechanisms by selecting only small scattering angles and thus large impact parameters. Contrary to Coulomb excitation at low energy, where multiple-step excitation is possible, single-step excitations dominate at energies well above the Coulomb barrier, usually simplifying the data analysis. The existence of a low-lying (meta-stable) 0_2^+ state can, however, influence the measured Coulomb excitation cross-sections and has to be taken into account explicitly. This effect is particularly important if the fragmentation products, which are to be excited in the electromagnetic field of a heavy target nucleus, have been produced with a certain probability in the meta-stable state. In that case the isomeric ratio of the beam has to be measured simultaneously with the Coulomb excitation probability in order to extract $B(E2)$ values (see e.g. the discussion in Ref. [14]).

Consequently a new device was designed to perform Coulomb excitation experiments of fragmentation products at intermediate energies with the LISE3 spectrometer [15] at GANIL. In addition to the standard detection systems for the tracking and identification of the incident and scattered ions, and for the γ rays emitted in-flight after Coulomb excitation, a dedicated setup was installed to measure conversion electrons emitted from unscattered beam particles in silicon detectors after implantation of the ions in a plastic scintillator. In this way the probability of the fragmentation products to be in an isomeric state could be measured and taken into account for the determination of $B(E2)$ values obtained from the Coulomb excitation process.

2. Experimental procedure and description of the setup

The exotic nuclei were produced by the fragmentation of an intense primary ^{78}Kr^{33+} beam at 70.1 A MeV, delivered by the coupled GANIL cyclotrons, on a natural Ni production target located between the two superconducting solenoids of the SISSI device [16]. The target of 125 μm thickness was inclined by 25° and followed by a carbon stripper foil of 10 mg/cm^2. After passing through the target the fragments had an average energy of 56 A MeV, and the stripper foil ensured that all produced nuclei exit the SISSI device in the charge state $Q = Z$. The reaction products of interest were selected and purified in the LISE3 spectrometer [15], operated in achromatic mode with a Be degrader of 215 μm thickness. The thickness of both target and degrader was optimized for the production of nuclei on the $N = Z$ line. The energy of the fragments after the degrader was ~48 A MeV, and the probability of the ions to be in charge state $Q = Z$ was greater than 80%. After the $B\rho$ selection of the second dipole magnet, only fully stripped ions reached the secondary target. With a primary beam intensity of 2.4e μA the intensity of the secondary ^{68}Se beam on the Coulomb excitation target was ~100 particles per second. The composition of the cocktail beam was regularly measured with reduced intensity using a silicon telescope placed before the Coulomb excitation setup.

The complete setup is illustrated schematically in Fig. 1 and described in more detail in the following sections. The associated electronics was based on an analog VXI-VME system and used the standard data-acquisition system of the GANIL facility.

2.1. Beam tracking

The incoming particles were tracked by a set of two micro-channel plate detectors (MCP) [17] of 65×65 mm^2 size, measuring secondary electrons produced in a thin emissive foil. The time difference between the first detector and the radio frequency of the cyclotrons provided the time