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Investigation of K-Isomers via Projectile Fragmentation in the Mass A∼180 Region

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Abstract. Gamma spectroscopy methods have been used to search for microsecond isomers among fragmentation products of 1 GeV/nucleon ^{208}Pb beam. Decays of several known K-isomers in the rare earth region of A ∼ 180 were observed, including the K=35/2 isomer in ^{179}W. Several new isomeric decays in the very neutron rich systems, such as ^{190}W, have been identified. The observed ground state rotational band will be discussed in the framework of the triaxial rotator model.

1. Introduction

Projectile fragmentation of relativistic heavy ions has proven to be a highly successful method of producing nuclei very far from the line of stability. Moreover, it was found that in fragmentation reactions near-yrast isomeric states are populated abundantly [1, 2]. Therefore, the combination of a projectile fragment separator, allowing the in-flight separation of exotic ions, together with gamma detection arrays mounted at the final focus of the spectrometer may be a powerful technique for spectroscopy studies at the limits of known nuclei.

The GSI Darmstadt SIS/FRS facility currently offers the unique possibility to study relativistic projectile-like fragments of heavy primary beams. Recently, an experiment has been carried out in which the fragmentation of the relativistic ^{208}Pb beam was used to produce and study neutron-rich rare earth nuclei around A∼180. The main goal was to search for high-spin K-isomers in order to obtain systematic data on the isomer-to-total production ratio which yields a better understanding of the fragmentation reaction mechanism. From the measured decay pattern of the isomers the nuclear structure of the exotic neutron rich nuclei could be extracted. In this contribution, first experimental results will be presented.

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2. Experimental Technique

The nuclei of interest were produced by the fragmentation of a ^{208}Pb beam at 1000 MeV/nucleon impinging on a 1.6 g/cm^2 beryllium target. The ^{208}Pb beam was provided by the SIS synchrotron in GSI with a typical intensity of 2*10^8 ions per 12 second beam spill. Projectile fragments were separated by the FRagment Separator (FRS) [3], operated in the standard achromatic mode, and identified in-flight ion by ion by time-of-flight, energy-loss and magnetic rigidity measurements. After slowing down in a variable aluminum degrader at the final focus of the FRS, identified ions were implanted in an aluminum catcher plate surrounded by four segmented Clover germanium detectors. On average, approximately 20% of the selected fragments were destroyed in the slowing down process. The total γ-ray efficiency of the Ge-detector array was measured to be approximately 8% at 661 keV. The effective detection efficiency was, however, reduced in practise due to the ions stopping in the catcher, which gave rise to a prompt burst of low energy X-rays and bremsstrahlung. This had the effect of "blinding", on average, 10 of the total 16 detector elements in each event. The experimental setup is shown in Fig. 1 which had a higher γ-ray detection efficiency compared to the pioneering experiment by Pfützner et al. [2].

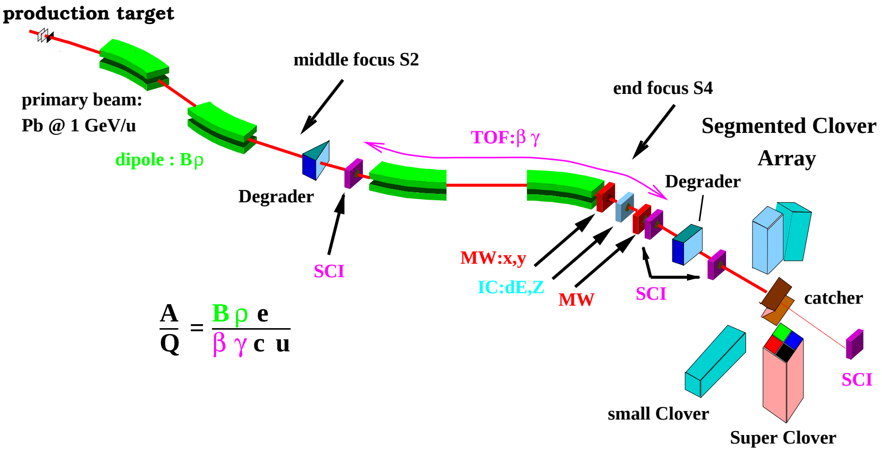

Fig. 1. Schematic picture of the FRS and the γ-ray spectroscopy setup.

In a single FRS setting about 16 different ions (4 elements, 4 isotopes each) were transmitted to the final focus. The time difference was measured between the implantation of the fragment in the stopper (as measured by the time signal from a plastic scintillator placed in front of the stopper) and the subsequently detected γ-ray in the array. This timing information was measured simultaneously using Time-to-Digital-Converters (TDCs) and Time-to-Amplitude-Converters (TACs) with ranges of 8 μs and 80 μs, respectively. The good time resolution of the TDCs allowed a clean removal of prompt events associated with bremsstrahlung and reactions in the stopper. Since the time of flight through the FRS was approximately 300 ns, this setup allowed the detection of isomeric decays with half-lives in the typical range of 100 ns to several hundred microseconds. Note however, that shorter lifetimes could also be detected if the decay branch by electron conversion was hindered for specific charge states of the ion (see below).

3. Results

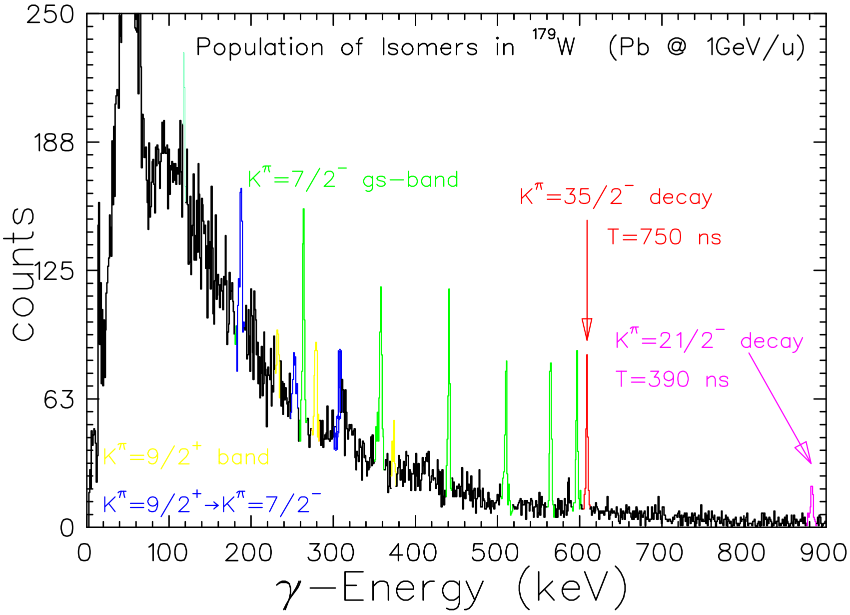

Fig. 2. Gamma-ray spectrum following the isomeric decays in ^{179}W produced by a fragmentation reaction of a ^{208}Pb beam at 1000 Mev/nucleon.

In order to verify the heavy ion identification procedure and also to collect data on the population probability of various K-isomers, a region of Hf-W-Os isotopes close to stability line was scanned in three FRS settings. In this region, several high-spin K-isomeric states are well known from previous studies using fusion-evaporation and deep inelastic reactions. Indeed, we observed decays from about 20 of these known isomers. Since their decay schemes are known, the isomeric ratios can be deduced, giving unprecedented information for testing models of angular momentum distribution following fragmentation reactions. One example is the known $K^\pi = 35/2^-$ isomer in ^{179}W [4] with a half-life of 750 ns which was populated with a probability of about 2% (see figure 2). This isomer corresponds to the highest discrete spin yet identified in a fragmentation product.

In ^{179}W another longlived state with $K^\pi = 21/2^+$ and a half-life of 390 ns was also populated. It decays first to the 9/2[624] excited band and then to the 7/2[514] ground state rotational band (see figure 2 and figure 3). The observed γ-ray intensities are smaller than for the higher-spin isomer ($K^\pi = 35/2^-$) due to the shorter half-life. The excited ^{179}W nuclei in its $K^\pi = 21/2^+$ state have a higher probability to decay during their flight path through the FRS.

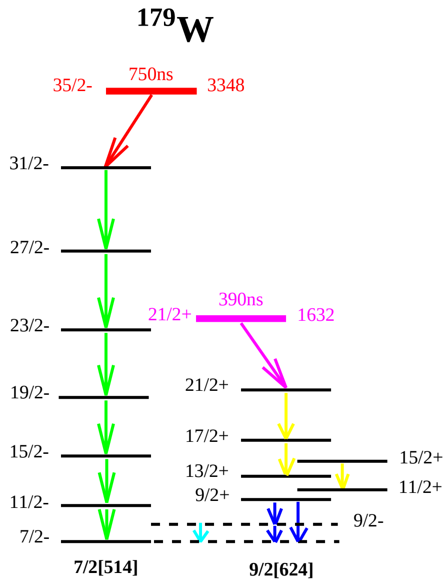

Fig. 3. Partial level scheme of ^{179}W.

In some cases the half-life limitation can be overcome for isomers whose neutral atoms have even shorter half-lives and decay by highly-converted transitions. Due to the blocking of the main conversion-electron decay channel, fully stripped fragments can be transported over a long path length with small intensity losses. In the present work, the ^{200}Pt nuclei were produced in its (7^-) isomer with a half-life of 14.3 ns for neutral atoms. A typical delayed γ-spectrum of ^{200}Pt is shown in figure 4 and confirms the results of Yates et al. [5].

This isomer usually decays via a highly-converted transition with an energy of 51 keV ($\alpha_T \sim 100$). In general, the projectile fragments are either fully stripped of their atomic electrons, or produced as hydrogen-like or helium-like ions before their flight through the FRS. Hence the isomer can only decay via the E2 γ-decay to the 5^- state, increasing the effective lifetime of the isomeric state. Once the ion is stopped in the aluminium catcher, it gains its atomic electrons and the E2 electron conversion partial decay widths take their usual values, allowing the isomer to decay with its (shorter) measured "atomic" lifetime.

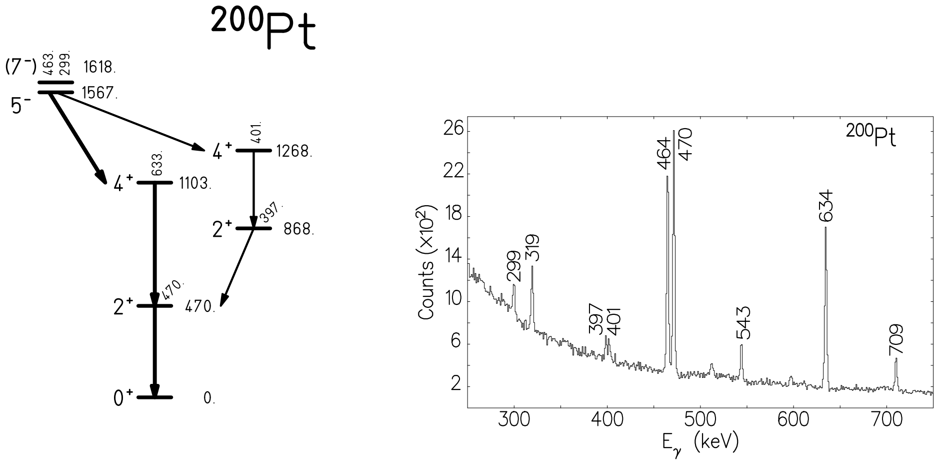

Fig. 4. Partial level scheme of ^{200}Pt (left) and γ-ray spectrum that result from the decay of the 14.3 ns isomer (right).

The observed level structure of ^{200}Pt is more similar to the triaxial or O(6) structure than to the vibrational or U(5) structure.

In the course of three other FRS settings, covering the boundary of known neutron-rich nuclei, several new isotopes in the mass 180-200 region were discovered. The spectroscopy of γ-transitions from the decay of K-isomers proves to be a novel method to access the structure of excited medium and high spin states in neutron rich unstable nuclei which can not be produced by other nuclear reactions. As a illustrating example, we give the case of $^{190}W_{116}$. Until this work, ^{190}W was the most neutron rich isotope of this element which had been identified and no excited states were known for this nucleus.

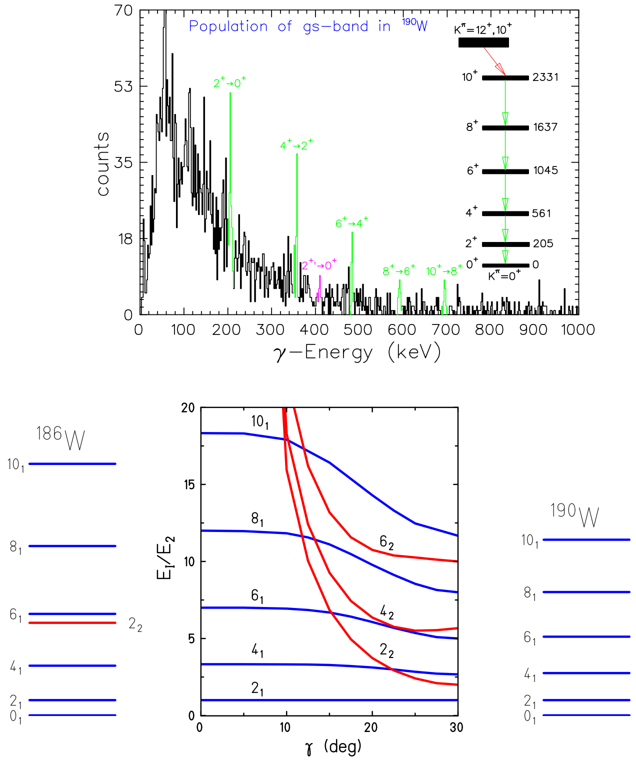

Fig. 5. Gamma-ray spectrum following the isomeric decay in ^{190}W produced in the fragmentation of a ^{208}Pb beam (top). Comparison of normalized ground state energies of ^{186}W and ^{190}W with calculated values of the triaxial rotator model for different deformation parameters γ (bottom).

Figure 5 shows the γ-spectrum recorded in coincidence with ^{190}W ions giving evidence for the decay of, most probably, a K^{π}=10^{-} isomer directly into the ground state rotational band. The systematics of this deformed region strongly suggest that the observed transitions at 207, 357, 485, 591 and 695 keV form a rotational cascade, built on the ground state of ^{190}W. However, the level energies differ from the expected I(I+1) rule for an axially symmetric roator. The energy ratio of the yrast 4^{+} and 2^{+} states yields a value of 2.72 which is close to the asymptotic limit of 2.5 for a triaxial nucleus with $\gamma = 30^{0}$ [6]. Figure 5 shows the normalized level energies of ^{190}W in comparison with the triaxial rotor prediction. Data for ^{186}W are also displayed which are well described with a much smaller triaxiality parameter $\gamma = 15^{0}$.

In the framework of the triaxial rotor model the reduced transition probability $B(E2;0^+ \rightarrow 2^+)$ is almost independent of the deformation parameter γ. Therefore, one can use the Grodzins empirical estimate [7] to determine the quadrupole deformation parameter β_2 from the level energy of the first excited state. Assuming that the observed 207 keV transition represents the yrast $2^+ \rightarrow 0^+$ decay, a value of $\beta_2 = 0.17$ can be determined for the ground-state deformation of ^{190}W.

4. Conclusions

The combination of the FRS with a γ-detection array improves considerably the resolution of the in-flight spectrometer. It is an efficient technique to investigate high spin isomeric states populated in a fragmentation reaction. Isomeric states with halflives in the range from 100 ns to several hundred microseconds were searched for among the fragmentation products of 1 GeV/nucleon ^{208}Pb beam. The K=35/2 isomer in ^{179}W was the highest spin states observed so far in projectile fragmentation. Half-life limitation can be overcome for isomers which decay by highly converted transitions. For highly stripped ^{200}Pt ions the decay of an isomeric state with an "atomic" half-life of 14.3 ns could be studied after a flight time of 300 ns through the FRS. Several new isomers in neutron-rich A=180-200 nuclei were observed providing information about nuclear structure of these nuclei. In case of ^{190}W, the isomer decays directly into the ground state band which allows the determination of the β_2- and γ-deformation parameters.

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