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Isomeric decay studies around ^{204}Pt and ^{148}Tb

Zs. Podolyák[1], S.J. Steer[1], S. Pietri[1], E. Werner-Malento[2,3], P.H. Regan[1], D. Rudolph[4], A.B. Garnsworthy[1], R. Hoischen[4], M. Górska[2], J. Gerl[2], H.J. Wollersheim[2], T. Kurtukian-Nieto[5], G. Benzoni[6], F. Becker[2], P. Bednarczyk[2,7], L. Caceres[2,8], P. Doornenbal[2], H. Geissel[2], J. Grębosz[2,7], A. Kelic[2], I. Kojouharov[2], N. Kurz[2], F. Montes[2], W. Prokopowicz[2,5], T. Saito[2], H. Schaffner[2], S. Tashenov[2], A. Heinz[9], M. Pfützner[3], M. Hellström[4], A. Jungclaus[8], L.-L. Andersson[4], L. Atanasova[10], D.L. Balabanski[11], M.A. Bentley[12], B. Blank[13], A. Blazhev[14], C. Brandau[1,2], J. Brown[12], A.M. Bruce[15], F. Camera[6], W.N. Catford[1], I.J. Cullen[1], Zs. Dombrádi[16], E. Estevez[5], C. Fahlander[4], W. Gelletly[1], G. Ilie[14], E.K. Johansson[4], J. Jolie[14], G.A. Jones[1], M. Kmiecik[7], F.G. Kondev[17], S. Lalkovski[10,15], Z. Liu[1], A Maj[7], S. Myalski[7], T. Shizuma[1,18], A.J. Simons[1], S. Schwertel[19], P.M. Walker[1], O. Wieland[6], and B.A. Brown[20]

[1] Department of Physics, University of Surrey, Guildford, GU2 7XH, UK
[2] GSI, Planckstrasse 1, 64291 Darmstadt, Germany
[3] IEP, Warsaw University, Hoża 69, 00681 Warsaw, Poland
[4] Department of Physics, Lund University, 22100 Lund, Sweden
[5] Universidad de Santiago de Compostela, 15706 Santiago de Compostela, Spain
[6] INFN, Universitá degli Studi di Milano, 20133 Milano, Italy
[7] The Henryk Niewodniczański Institute of Nuclear Physics, 31342 Kraków, Poland
[8] Departamento de Fisica Teórica, Universidad Autonoma de Madrid, 28049 Madrid, Spain
[9] WNSL, Yale University, New Haven, CT 06520-8124, USA
[10] Faculty of Physics, University of Sofia, 1164 Sofia, Bulgaria
[11] Inst. for Nucl. Research and Nucl. Energy, Bulgarian Academy of Sciences, 1784 Sofia, Bulgaria
[12] Dept. of Physics, University of York, Heslington, York, Y01 5DD, UK
[13] CENBG, Le Haut Vigneau, BP. 120, 33175 Gradignan Cedex, France
[14] IKP, Universität zu Köln, 50937 Köln, Germany
[15] School of Engineering, University of Brighton, Brighton, BN2 4GJ, UK
[16] Institute for Nuclear Research, ATOMKI, 4001 Debrecen, Hungary
[17] Nuclear Engineering Division, Argonne National Laboratory, Argonne, IL 60439, USA
[18] Japan Atomic Energy Agency, Kyoto 619-0215, Japan
[19] Physik Department E12, Technische Universität München, Garching, Germany
[20] Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, USA

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Abstract. Relativistic energy projectile fragmentation of ^{208}Pb has been used to produce a range of exotic nuclei. The nuclei of interest were studied by detecting delayed gamma rays following the decay of isomeric states. Experimental information on the excited states of the neutron-rich N = 126 nucleus, ^{204}Pt, following internal decay of two isomeric states, was obtained for the first time. In addition, decays from the previously reported isomeric $I = 27\hbar$ and $I = (49/2)\hbar$ states in ^{148}Tb and ^{147}Gd, respectively, have been observed. These isomeric decays represent the highest spin discrete states observed to date following a projectile fragmentation reaction, and opens further the possibility of doing 'high-spin physics' using this technique.

PACS. 25.70.Mn Projectile and target fragmentation – 29.30.Kv X- and gamma-ray spectroscopy

1 Introduction

First results from a major new initiative of experiments focusing on the study of the internal structure of nuclei at the extremes of N/Z ratio using isomer spectroscopy are reported. These experiments represent the first of the Stopped Beam section of the *Rare Isotopes Investigations at GSI* (RISING) project. Exotic nuclei were synthesized using relativistic projectile fragmentation of E/A = 500–1000 MeV beams of ^{58}Ni, ^{107}Ag, ^{208}Pb.

The present paper presents selected highlightss of the initial experimental results from this highly successful campaign, with the focus on heavy systems populated in the fragmentation of the ^{208}Pb projectile. Some results obtained on the N $\sim$ Z nuclei are discussed in [1].

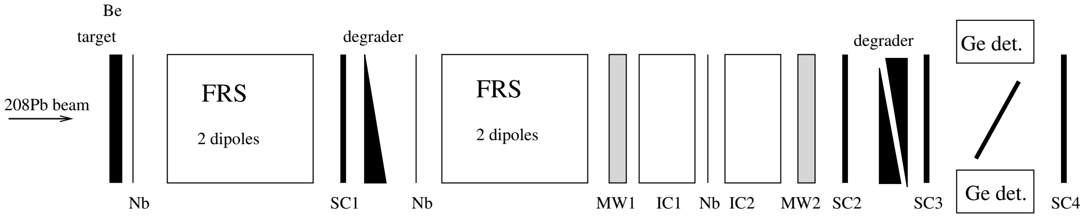

Fig. 1. Schematic view of the experimental setup. For details see the text.

2 Experimental details

Fragmentation has proven to be an efficient tool to produce exotic nuclear species. When projectile fragmentation is combined with high sensitivity gamma detection arrays, structure information can be gained for otherwise inaccessible nuclei. The highest sensitivity is achieved with the so-called isomer decay spectroscopy. In this technique the delayed gamma rays are correlated with the individually identified ions, therefore there is a minimum of background radiation. Information on the excited states populated in this way can be obtained with only some 1000 nuclei produced. Heavy nuclear species were populated in relativistic energy projectile fragmentation. A beryllium target of thickness 2.5 g/cm^2 was bombarded with an E/A = 1 GeV ^{208}Pb beam provided by the SIS accelerator at GSI, Darmstadt, Germany. The nuclei of interest were separated and identified using the FRagment Separator (FRS) [2] operated in standard achromatic mode. The setup is shown in figure 1. The achromatic wedge-shaped aluminum degrader in the intermediate focal plane of the separator had an average thickness of 4900 mg/cm^2. Niobium foils of thicknesses 221 mg/cm^2 and 108 mg/cm^2 were placed after the target and the degrader, respectively, in order to maximise the electron stripping.

The mass-to-charge ratio of the ions, A/q, was determined from the performed time of flight (measured between two scintillator detectors SC1 and SC2) and magnetic rigidity measurements in the second part of the FRS (the ions were tracked using position information from SC1 and the multiwire detectors MW1 and MW2). The energy deposition of the fragments was measured as they passed through two gas ionisation chambers (IC1 and IC2) separated by a 221 mg/cm^2 Nb foil. Following this, they were slowed down in a variable thickness aluminum degrader and finally stopped in a ~7–9 mm thick plastic catcher. Scintillator detectors were placed both in front of and behind the catcher (SC3 and SC4), allowing the offline suppression of those fragments destroyed in the slowing down process or those which were not stopped in the catcher. The identification of the fragments is based on the determined A/q, the energy loss in the ionisation chambers (≈Z), and the longitudinal position of the nuclei at the intermediate and final focal planes of the FRS. For more details about the identification procedure see [3].

The plastic catcher was surrounded by the high-efficiency, high granularity Stopped RISING γ-ray spectrometer [4]. It consists of 15 Euroball cluster Ge-detectors, and in the present configurations has nearly 4π geometry. Time-correlated gamma decays upto a delay time of 400 μs from individually identified nuclear species have been measured, allowing the clean identification of isomeric decays in a wide range of exotic nuclei. In this simple form (using a passive stopper) the technique is sensitive to isomeric decays with lifetimes between 100 ns and 1 ms. The lower limit arrises form the flightime through the fragment separator (≈300 ns); the upper limit is from the necessity to correlate the delayed gamma rays with the implanted ion. Longer correlation times can be obtained by using active stoppers.

3 Along the N = 126 line

Information on the neutron-rich N = 126 nuclei is very scarce. The lack of information is due to the difficulties in populating these nuclei. Below the doubly magic ^{208}Pb nucleus there is experimental information on only three isotones: ^{207}Tl, ^{206}Hg and ^{205}Au. While in both ^{207}Tl [5] and ^{206}Hg [6] excited states have been observed (including isomeric states, see figure 2), in ^{205}Au only the ground state is known ($I^\pi = (3/2^+)$ [7]).

3.1 ^{206}Hg

The yrast states of ^{206}Hg have been previously studied using deep-inelastic reactions [6]. The partial level scheme together with the dominant shell model configurations is shown in figure 2.

The present observation of isomeric states in ^{206}Hg is important for reaction studies. The delayed gamma-ray spectrum is shown in figure 3. Population of the 10^+ and 5^- isomeric states relative to the ground state, the so called isomeric ratio, will be determined.

^{206}Hg was populated by removing two protons from the ^{208}Pb beam. Non-direct population of ^{206}Hg states, by one proton removal to excites states in ^{207}Tl followed by proton evaporation, involves intermediate states above the neutron evaporation threshold and it is expected to be small [8]. Therefore ^{206}Hg is synthesized in a direct two-proton knockout (also called cold fragmentation) reaction.

Two proton removal cross sections, from E/A = 1 GeV ^{208}Pb on a ^{9}Be target, were calculated by Tostevin [8]. The two-protons were assumed to be uncorrelated and both the stripping and the diffraction mechanisms were considered. The direct population of the individual states 10^+ (configuration $\pi h^{-2}_{11/2}$), 8^+ ($\pi h^{-2}_{11/2}$), 7^- ($\pi h^{-1}_{11/2} d^{-1}_{3/2}$) and

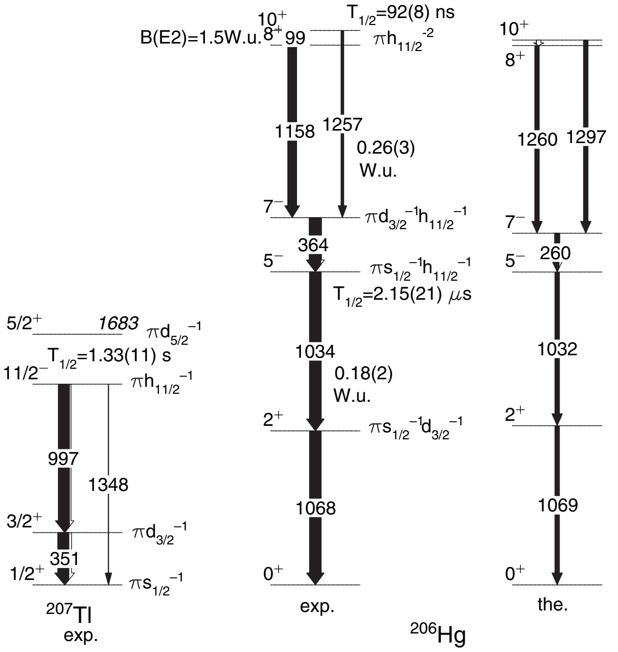

Fig. 2. Partial level schemes of ^{207}Tl [5] and ^{206}Hg [6]. The result of the shell model calculation for ^{206}Hg is shown on the right hand side of the figure.

5^- ($\pi h^{-1}_{11/2}s^{-1}_{1/2}$) has been estimated. The calculated cross sections result in a predicted ratio of isomeric ratios of the 10^+ and 5^- isomers of 21:83 [8]. This value, and the individual isomeric ratios, will be compared with those extracted from the present experiment. Note that the 5^- isomer has been previously observed in a former fragmentation experiment, and an upper limit of the isomeric ratio has been determined [9].

3.2 ^{204}Pt

^{204}Pt has four protons less than the doubly magic ^{208}Pb nucleus. Its yrast structure is expected to be dominated by the proton-hole orbitals $\pi d_{3/2}$, $\pi s_{1/2}$, $\pi h_{11/2}$ and possible $\pi d_{5/2}$ (see level scheme of ^{207}Tl in figure 2.). Its level scheme is expected to be similar to that of ^{206}Hg.

Gamma-ray spectra associated with ^{204}Pt are shown in figure 4. Two isomeric decays have been observed, with a longer lifetime associated to the 872 keV and 1123 keV transitions, and a shorter to the 1061 keV, 1158 keV and 96 keV gamma-lines. Shell-model calculations are being performed using the OXBASH code [10], and results on ^{206}Hg are shown in figure 2. The empirical interaction matrix elements are from [11] and are based on those of Kuo and Herling [12]. The experimental proton-hole energies were taken from the experimental level scheme of ^{207}Tl, as shown in figure 2. There is a rather good agreement between theory and experiment for ^{206}Hg (note that the interaction matrix elements were obtained by fitting on a range of nuclei, including the 2^+ and 5^- states of ^{206}Hg [11]). For ^{204}Pt the interpretation of the results and comparison with shell-model calculations are in progress.

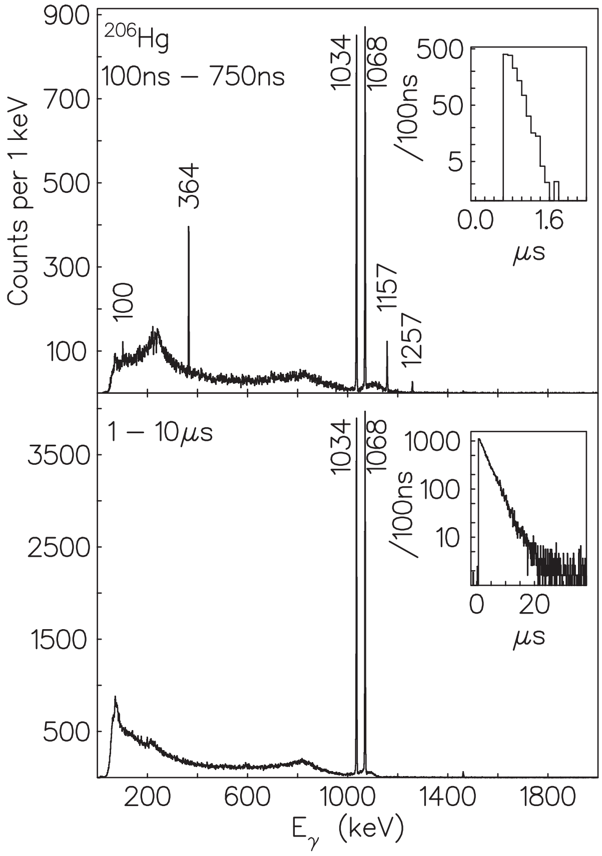

Fig. 3. Delayed gamma-ray spectra associated with ^{206}Hg. Note that the shape of the background around ~300 keV is unphysical, and it is due to used data analysis method.

4 Population of high-spin states

The fragmentation process can be described by the abrasion-ablation model rather successfully [13]. A key aspect of this fragmentation model is the estimation of the excitation energy and angular momentum of the prefragments. Such information can be obtained by studying the population of long lived states. Experimentally we cannot determine the population of a single state with a given angular momentum, but only the total population of all the states decaying into the level of interest. Therefore, the study of the population at high angular momentum from the tail of the distribution, provides a much more stringent test of the theory than populations at lower angular momenta. Previous studies showed that in order to understand the population of high-spin states two sources of angular momenta have to be considered: from the single-particles knocked out in the abrasion phase of the fragmentation, and a collective angular momentum related to 'friction' (and eventually to the binding energy of the knocked out nucleons) [14].

In order to study the population of isomeric states with high angular momenta a measurement with the magnetic rigidity setting of the FRS centred on ^{147}Gd was performed. Several previously known isomeric states were observed, including the high-spin isomers $I = 27\hbar$ in

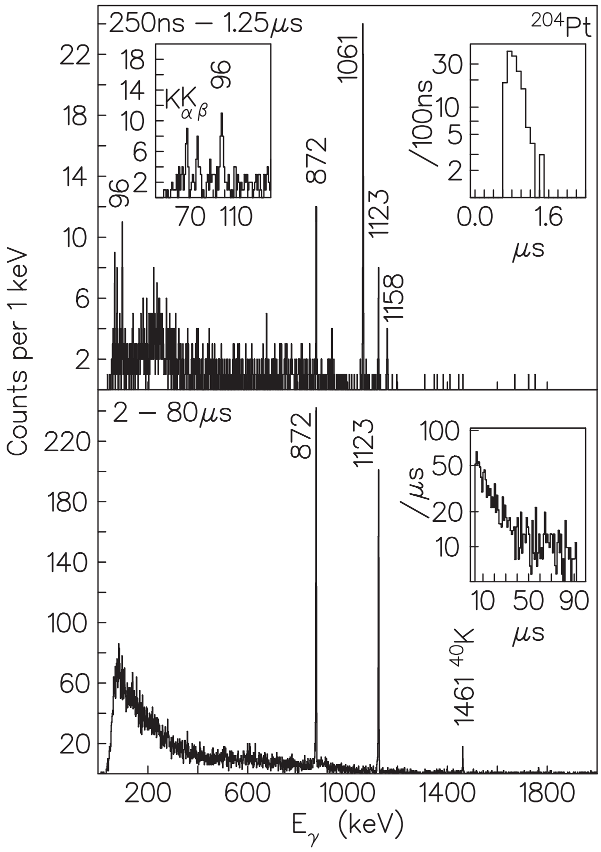

Fig. 4. Delayed gamma-ray spectra associated with ^{204}Pt. Note that the shape of the background around ∼300 keV is unphysical, and it is due to used data analysis method.

^{148}Tb [15] and $I = (49/2)\hbar$ in ^{147}Gd [16] (see figure 5). These are the highest spin discrete states observed to date following a projectile fragmentation reaction. The isomeric ratios will be determined and compared with predictions of different fragmentation models.

5 Conclusions

A wide range of nuclei have been populated in fragmentation of relativistic energy ^{208}Pb. The experiment has been performed at the FRS-RISING setup at GSI and was devoted to both nuclear structure and fragmentation reaction studies. Preliminary results have been presented, with the highlights on: (i) nuclei along the N = 126 line, especially the first information on excited states in the four proton-hole nucleus ^{204}Pt, and (ii) high angular momentum states populated in the region around ^{148}Tb.

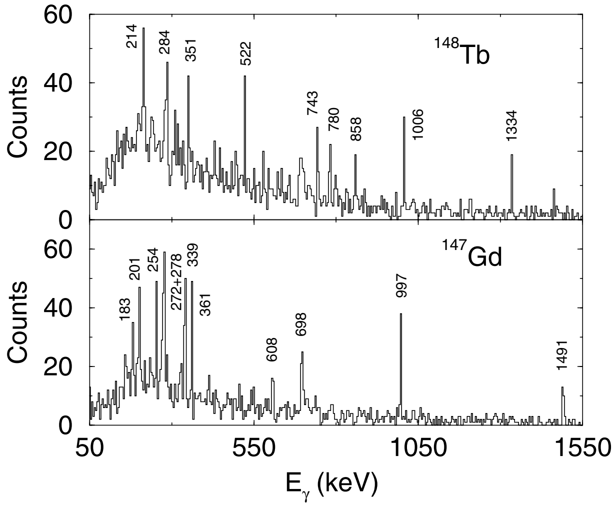

Fig. 5. Delayed gamma-ray spectra associated with ^{148}Tb and ^{147}Gd. The transitions labelled with their energies in keV originate from the decay of the high spin isomers $I = 27\hbar$ in ^{148}Tb [15] and $I = 49/2\hbar$ in ^{147}Gd [16], respectively.

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