STUDY OF DEFORMATION EFFECTS IN THE CHARGED PARTICLE EMISSION FROM ^{46}Ti* *

M. Brekiesz[a], P. Papka[b,c], A. Maj[a], M. Kmiecik[a], C. Beck[b]
P. Bednarczyk[a,d], J. Grębosz[a], F. Haas[b], W. Męczyński[a]
V. Rauch[b], M. Rousseau[b], A. Sànchez i Zafra[b], J. Styczeń[a]
S. Thummerer[e], M. Ziębliński[a] and K. Zuber[a]

[a]The H. Niewodniczański Institute of Nuclear Physics
Polish Academy of Sciences, Kraków, Poland
[b]IReS IN2P3-CNRS/Université Louis Pasteur, Strasbourg, France
[c]Department of Physics, University of York, Heslington, UK
[d]Gesellschaft für Schwerionenforschung, Darmstadt, Germany
[e]Hahn-Meitner Institute, Berlin, Germany

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The ^{46}Ti* compound nucleus, as populated by the fusion–evaporation reaction ^{27}Al + ^{19}F at the bombarding energy of 144 MeV, has been investigated by charged particle spectroscopy using the multidetector array ICARE at the VIVITRON tandem facility of the IReS (Strasbourg). The light charged particles have been measured in coincidence with evaporation residues. The CACARIZO code, a Monte Carlo implementation of the statistical model code CASCADE, has been used to calculate the spectral shapes of evaporated α-particles which are compared with the experimental spectra. This comparison indicates the possible signature of large deformations of the compound nucleus.

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1. Introduction

In the recent years, there have been a number of experimental and theoretical studies aimed at understanding the effects of large deformations in the case of light-mass nuclei. The very elongated prolate or triaxial shapes were deduced from the spectra of the Giant Dipole Resonance (GDR) from the decay of ^{46}Ti* [1, 2] and ^{45}Sc* [3]. The results were consistent with predictions of the LSD (Lublin–Strasbourg Drop) model [4, 5], in which the

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large deformations are ascribed to the Jacobi shape transition. The large deformations were also indicated by the measurement of energy spectra and angular distributions of the light charged particles (LCP) originated from the decay of ^{44}Ti* [6] as formed in two fusion reactions ^{16}O + ^{28}Si [7] and ^{32}S + ^{12}C [8]. In addition, a number of superdeformed bands of discrete γ-ray transitions were discovered in selected $N = Z$ nuclei belonging to this mass region (*e.g.* [9,10]). In this paper, we focus on the measurement of the LCP spectra in coincidence with evaporation residues (ER) for the reaction ^{27}Al + ^{19}F at a bombarding energy of $E_{\rm lab}(^{27}{\rm Al}) = 144$ MeV. In the following sections the experimental setup, the data analysis and the discussion of the preliminary results are presented.

2. The experimental setup and experimental results

The experiment was performed at the VIVITRON tandem facility of the IReS Strasbourg (France), using the multidetector array ICARE and a large volume ($4'' \times 4''$) BGO detector. The ^{46}Ti* compound nucleus (CN) was populated by the ^{27}Al + ^{19}F reaction at the 144 MeV bombarding energy of the aluminium beam. The inverse kinematics reaction was chosen to increase the residual nuclei velocity in order to resolve the highest Z (the slowest evaporation residues) produced in the reaction.

A fluorine target (LiF: 150 μg/cm^2 of F, 55 μg/cm^2 of Li) on a thin carbon backing (20 μg/cm^2) was used. The excitation energy of the ^{46}Ti nuclei was 85 MeV and the maximum angular momentum $L_{\rm crit} \approx 35\,\hbar$.

High-energy γ-rays from the GDR decay were measured using the BGO detector. The heavy fragments were detected in six gas-silicon telescopes (IC), each composed of a 4.8 cm long ionization chamber with a thin Mylar entrance window followed by a 500 μm thick surface barrier silicon detector. The IC were located at $\Theta_{\rm lab} = \pm 10^\circ$ in three distinct reaction planes. The in-plane detection of coincident LCP's was done using ten triple telescopes (40 μm Si, 300 μm Si, 2 cm CsI(Tl)) placed at forward angles ($\Theta_{\rm lab} = \pm 20^\circ, \pm 25^\circ, \pm 30^\circ, \pm 35^\circ, \pm 40^\circ$), eighteen two-element telescopes (40 μm Si, 2 cm CsI(Tl)) placed at forward and backward angles ($\pm 45^\circ \leq \Theta_{\rm lab} \leq \pm 130^\circ$) with $\Delta\Theta = 5^\circ$ angular step, and finally four other IC telescopes located at the most backward angles ($\pm 150^\circ \leq \Theta_{\rm lab} \leq \pm 165^\circ$). The opening angle of the detectors was $\Delta\Theta \approx 3^\circ$. The IC were filled with isobutane at a pressure of 40.5 mbar for the forward angles and of 49.6 mbar in backward angles, thus allowing for simultaneous measurement of both heavy and light fragments.

The energy calibrations of various telescopes of the ICARE multidetector array were done using radioactive ^{228}Th and ^{241}Am α-particle sources in the 5–9 MeV energy range and elastic scattering of 45 MeV ^{11}B, 53 MeV

^{16}O and 144 MeV ^{27}Al from ^{197}Au target. In addition, the ^{12}C(^{16}O,α)^{24}Mg* reaction at 53 MeV was used to provide known energies of α-particles feeding the ^{24}Mg excited states, thus allowing for an accurate calibration of the backward angle detectors.

Exclusive energy spectra of the α-particles emitted in the laboratory frame at the angles $\Theta_{\rm lab} = 25°, 35°, 45°$ in coincidence with $Z = 18$, 19, 20 measured by ionization chamber located at $\Theta_{\rm lab} = -10°$ are shown in Fig. 1 by the solid points. All measured spectra have the expected Maxwellian shape with an exponential fall-off at high energy. The dashed and solid lines are the results of statistical model calculations.

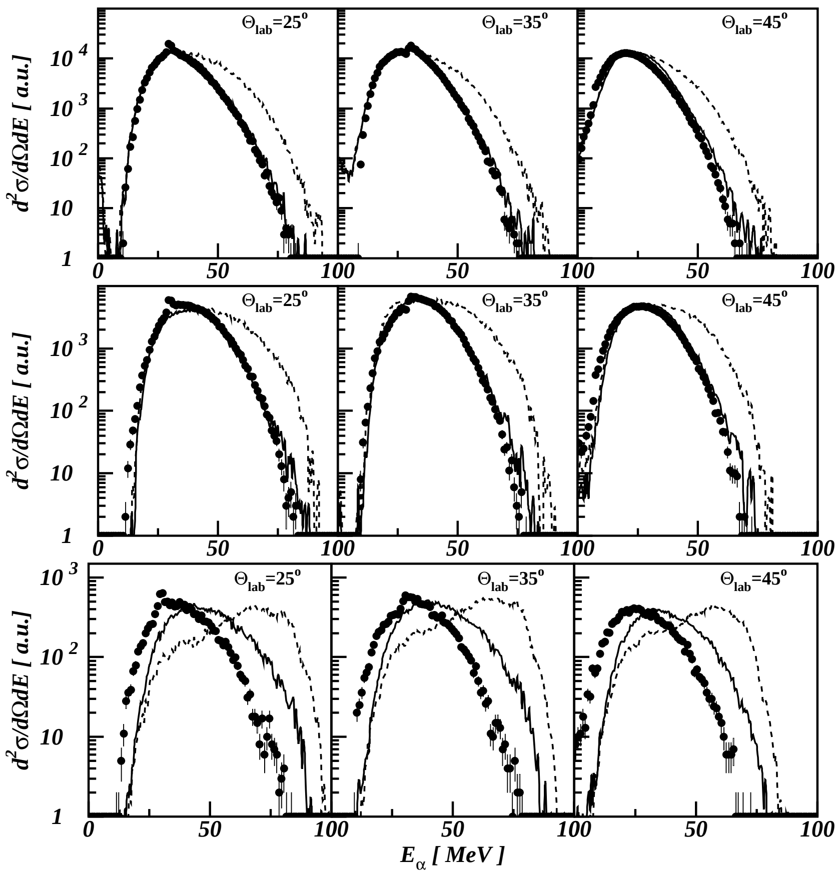

Fig. 1. Experimental (points) and calculated (lines) α-particle energy spectra for $\Theta_{\rm lab} = 25°, 35°, 45°$ in coincidence with three different ER's ($Z = 18$ upper row, $Z = 19$ middle row, $Z = 20$ bottom row) detected in IC at $\Theta_{\rm lab} = -10°$. The calculations were carried out with deformation parameters for RLDM (dashed line) and for very elongated prolate (solid line) shapes (see text).

3. Statistical model calculations and discussion

The analysis of LCP data has been performed using CACARIZO, the Monte Carlo version of the statistical model code CASCADE [11], which is based on the Hauser–Feshbach formalism [12–14]. The compound nucleus decays are followed step-by-step and evaporated LCP's and neutrons are recorded in an event file. The main practical advantage of the code is that the effective experimental geometry (solid angle and position) of the ICARE detectors is taken into account in the calculation of the charged particle energy spectra. Therefore, one can on the event-by-event basis, convert the calculated energies into the laboratory frame for an easier comparison of the calculated and measured spectra.

The sensitivity of various parameters for the statistical description, as the nuclear level densities and barrier transmission probabilities, has been discussed in detail in Ref. [14]. In the calculations, the transmission coefficients T_l of all competing evaporation channels have been evaluated with optical model parameters for spherical nuclei [15]. The choice of the transmission coefficients is of particular importance in the near-barrier region, where they define the emission probability of low-energy particles. Above the barrier, the kinetic energy of LCP is higher than the potential barrier and the choice of T_l parameterizations is less important (see Ref. [14]). The high-energy part of α-particle spectra depends on the available phase space, which is obtained by the statistical model from the spin-dependent level density. The level density is calculated using the Rotating Liquid Drop Model (RLDM) [11] and can be changed using the deformability parameters. Larger deformations lower the yrast line, what increases the level density at higher available excitation energy of the final nucleus after α emission, thus reduce α-particle energies. In the code, the yrast line is parameterized with deformability parameters δ_1 and δ_2: $E_L = \hbar^2 L(L+1)/2\Im_{\rm eff}$ with $\Im_{\rm eff} = \Im_{\rm sphere}(1 + \delta_1 L^2 + \delta_2 L^4)$ [13], where $\Im_{\rm eff}$ is the effective moment of inertia, $\Im_{\rm sphere} = (2/5)A^{5/3}r_0^2$ is the rigid body moment of inertia of the spherical nucleus and r_0 is the radius parameter (set to 1.3 fm in the present calculations).

For the calculations, two different deformation sets are applied with different yrast line shape parameterizations. Fig. 2 illustrates the yrast line for a spherical rigid body and the two yrast lines used in present calculations: for shapes following the RLDM predictions (spherical up to $L = 24\,\hbar$ and nearly spherical above) and for very elongated prolate shapes ($\delta_1 = 4.7 \times 10^{-4}$, $\delta_2 = 1 \times 10^{-7}$). The latter values of the deformability parameters are taken from the previous studies on the ^{44}Ti nucleus [6–8]. The angular momentum distribution used in the statistical model calculation is dependent on the diffusivity parameter ΔL and the critical angular momentum for fusion $L_{\rm crit}$.

For the final calculations the value of $\Delta L = 1$ is used [12–14] and the value of $L_{\mathrm{crit}} = 35\,\hbar$ is deduced from the fusion cross section data [16].

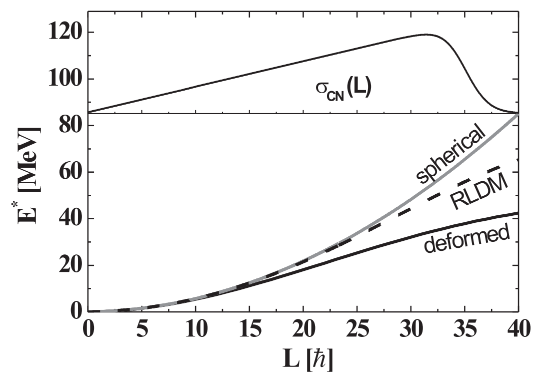

Fig. 2. The yrast lines for spherical rigid body, for shapes predicted by the RLDM and for very elongated prolate shapes (see text) of the ^{46}Ti compound nucleus. The assumed angular momentum distribution of the compound nucleus is shown on the top.

The dashed lines in Fig. 1 show the energy spectra of α-particles predicted by CACARIZO assuming the RLDM yrast line. It can be observed that average energies of α-particles measured in coincidence with all ER ($Z = 18$, 19, 20) are systematically lower than predicted.

The solid lines in Fig. 1 illustrate the calculations of CACARIZO, which were obtained using the yrast line deformability parameters corresponding to large prolate deformations (such yrast line corresponds, on average, to the yrast line of a rigid body with the deformation parameter $\beta \approx 0.6$). As can be seen, such parameterization results in a very good overall reproduction of the spectral shapes of the α-particles detected in coincidence either with $Z = 18$ or with $Z = 19$.

However, the spectra associated with $Z = 20$ are in disagreement with the calculations. In order to improve the agreement, an even more deformed yrast line (rather unrealistic) would be required. One should note here, that the condition for the α-particle and the $Z = 20$ residue to belong to the same event induces a severe narrowing of the available phase space to only the highest angular momenta of CN. This might suggest indeed the occurence of very elongated shapes around $L = 30\,\hbar$, as expected for the Jacobi shape transition, confirming the GDR results of Ref. [2].

However, a more refined analysis, including also a consistent treatment of the energy spectra of the protons, the LCP angular correlations and the high-energy γ-ray spectra, will have to be undertaken in order to confirm such hypothesis.

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