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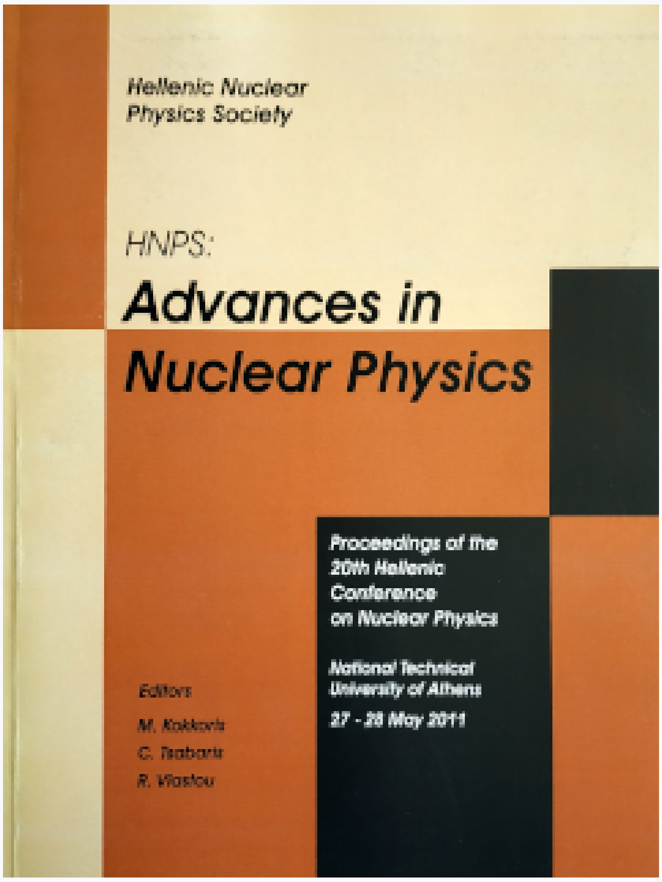

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Measurement of Nuclear Lifetimes and B(E2) Values in ^{130}Xe as a Test for E(5) Symmetry

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Abstract

As a continuation of the previous measurement in ^{128}Xe [1], [2], [3], another E(5) candidate, ^{130}Xe, has been studied through the novel experimental technique Coulex-plunger in inverse kinematics. The measurements have been undertaken at the JYFL accelerator facility in Jyväskylä, Finland. For the purpose of this experiment the Cologne plunger was coupled to the JYFL cyclotron which delivered the ^{130}Xe beam. Excited states in ^{130}Xe were populated by the ^{nat}Fe(^{130}Xe, ^{130}Xe*) reaction at E(^{130}Xe)=500 MeV and the subsequent de-excitations were detected in the JUROGAM γ-ray array. By applying the well known Differential Decay Curve Method (DDCM) [4], lifetimes of the 2_1^+ and 4_1^+ excited states were determined. In addition, since the investigated nucleus is excited through the Coulomb interaction, it is possible to perform a full Coulomb excitation analysis of the data using the computer code GOSIA [5] which will allow the determination of B(E2) values of the transitions up to the 6_1^+ excited state.

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1 Motivation

Apart from the single particle and two nucleon excitations, collective modes, in which many nucleons participate in the excitation, are also observed in the excitation spectra of many nuclei. These modes are understood in nuclear structure as vibrations and rotations of the whole nucleus and the nuclei that display this behavior are categorized into three groups: spherical harmonic vibrators, axially symmetric rotors and axially asymmetric rotors also called γ-soft nuclei. In 1975 a group theoretical approach of the collective behavior, the Interacting Boson Approximation (IBA) was introduced by Arima and Iachello [6]. Within this approximation the three aforementioned "geometrical" pictures of nuclear collective excitations are described in terms of dynamical symmetries of the U(6) Lie algebra. Since there are three different chains of subgroups of U(6), three possible dynamical symmetries are obtained, namely the U(5), the SU(3) and the O(6) chain which correspond to the vibrators, axially deformed rotors and γ-soft nuclei respectively. In year 2000, Iachello introduced two new dynamical symmetries, the so called X(5) and E(5) critical point symmetries, which describe shape phase transitions between the three limits [7], [8]. In particular, X(5) describes nuclei which lie at the critical point of the U(5) to SU(3) shape phase transition, whereas E(5) describes nuclei which undergo a shape phase transition between the U(5) and the O(6) limit. Both the E(5) and X(5) critical-point symmetries provide parameter-free predictions (except for scale) for energies and reduced transition probabilities.

To date, the X(5) symmetry is assumed to be well established as nuclei such as Os isotopes [9] and N=90 isotones [10] , [11] among others, display the X(5) features. The E(5) symmetry, on the other hand, was initially reported to be realized in ^{134}Ba [12]. Since then many nuclei have been proposed as possible candidates for the E(5) symmetry [13] but none of them appears to have a good overall agreement with the theoretical predictions especially in terms of the reduced transition strengths of the γ-transitions depopulating the low-lying levels of the ground band as well as the γ and β bands. Consequently, more experimental effort is needed in order to confirm the E(5) symmetry in nuclear structure. Among the E(5) candidates proposed, ^{128}Xe and ^{130}Xe have been underlined as two of the most promising ones. As a result of our previous measurement, ^{128}Xe has already been ruled out from the E(5) candidates list. This fact motivated a continuation measurement for the case of ^{130}Xe.

2 Experimental Setup

The experimental setup is identical with the one used in the ^{128}Xe experiment and is shown in Fig.1.

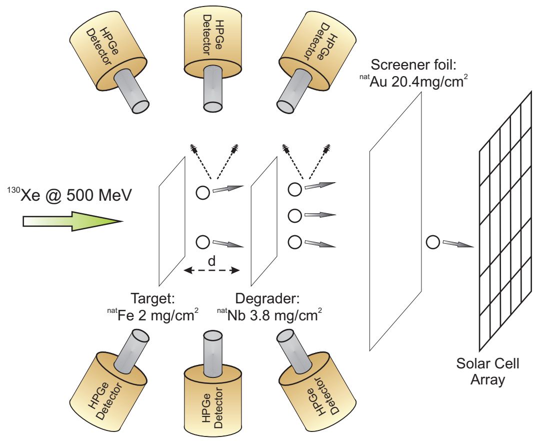

Fig. 1. The experimental setup for the Coulex-Plunger technique is shown in the figure. The ^{130}Xe beam passes through the target and the degrader with an initial energy of 500 MeV. As a result Xe, Fe and Nb recoils are flying towards the endcap of the beamline where the solar cell array is. Therefore, a Au screening foil is placed in front of the solar cells, thick enough to cut all other recoils apart from iron. As a result the detection of the iron recoils gives a clear trigger for the reaction.

The ^{130}Xe beam, which was delivered by the Jyväskylä cyclotron, impinges on the 2 mg/cm^2 thick ^{nat}Fe target with an energy of 500 MeV. The Coulomb-excited ^{130}Xe nuclei along with the iron recoils pass through the degrader foil which in this case is a 3.8 mg/cm^2 thick Nb foil. At the endcap of the beamline a silicon based solar cell array is placed which covers an angular span between 6^o and 38^o around the beam axis. The array is covered with a 20 mg/cm^2 Au foil which is thick enough to stop the Nb and the Xe recoils but not the Fe recoils. The iron recoils are subsequently detected by the array of solar cells and this signal is used as a trigger for the reaction. The setup is surrounded by the JUROGAM γ-ray array which consists of 40 High Purity Ge detectors (HPGe) arranged in four different rings placed at angles $\theta = 157.6^o$, $\theta = 133.57^o$, $\theta = 104.5^o$ and $\theta = 75.5^o$ with respect to the beam. Using this setup, particle-γ as well as particle-γ-γ coincidences between the Fe recoils hitting the solar cells and the γ-rays detected in the four separate rings were recorded at 11 plunger distances ranging from 7 to 400 μm.

A typical plunger spectrum is shown in Fig.2.

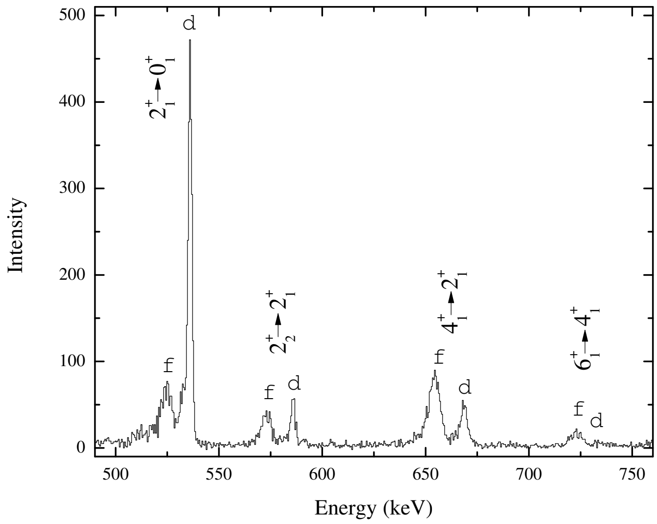

Fig. 2. A typical particle gated γ-γ-spectrum is shown where the four strongest transitions of the Coulomb excited ^{130}Xe are indicated. Marked with "f" and "d" are the "flight" and "degraded" components of each transition. The spectrum is taken at an intermediate plunger distance of 30 μm therefore both shifted and unshifted components are clearly visible.

3 Extraction of lifetimes using the Differential Decay Curve Method

The data were first sorted using the code "Grain" [14] and they were subsequently analyzed. The well known DDCM procedure for the γ-γ-coincidence as well as for the "singles" mode case was applied as described in [4] and [15] in order to determine lifetimes of excited states from which one can extract the B(E2) values of the involved transitions. For the particle-γ-γ-coincidence case one needs to gate on the flight component of the direct feeder of the level of interest. Due to low statistics in the γ-γ-matrices, it was only possible to gate on the flight component of the $4^+_1 \rightarrow 2^+_1$. The intensities of the shifted component of the depopulating transition, $2^+_1 \rightarrow 0^+_1$, are fitted with second-order polynomials, as described in [4], and the derivative of these polynomials are fitted to the intensities of the stopped component. This way, two "decay curves" are obtained for the Doppler-shifted and unshifted components which are used to extract the lifetime of the 2^+_1 level at each target-to-stopper distance giving a total weighted mean value of 14.6 (4) ps. The individually determined lifetimes and their associated errors are then plotted on a so-called τ-plot versus the target-to-stopper distance, x, which is shown on the left side of figure 3.

For the particle-γ-coincidence case ("singles") the procedure is similar. Since, in this case, there is no gate on the direct feeder of the level of interest, one

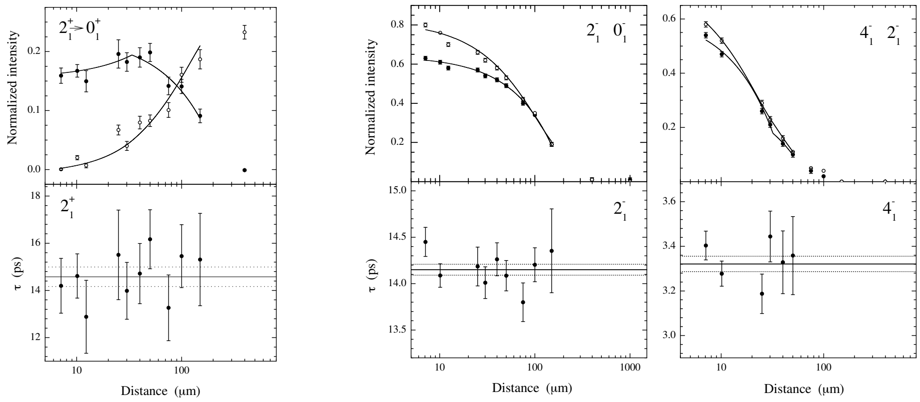

Fig. 3. The τ-plots that resulted from the coincidence (left) and the singles (right) analysis are shown in the figure. For the fitting of the decay curves and the extraction of the lifetimes, the computer program NAPATAU [16] was used.

needs to also measure the intensities of all possible feeders. The statistics in this case are better thus allowing the determination of the 2^+_1 and 4^+_1 lifetimes which are 14.1(1) and 3.32 (3) ps respectively. The errors given here, as in the case of the γ-γ-coincidence, are the statistical errors and do not include any possible systematic errors which are yet to be determined. The corresponding τ-plots for the "singles" analysis are shown on the right side of figure 3.

4 Ongoing coulomb excitation analysis

As in the case of the ^{128}Xe experiment, it is possible to take advantage of the reaction mechanism in order to determine the transitions strengths of the transitions involved. The Xe nuclei were excited through the very well known Coulomb interaction thus if one knows the matrix elements connecting the excited levels, one could calculate the excitation cross section for each state and then, taking into account the geometry of the experimental setup, and the efficiency of the detectors, one could calculate the intensities of the photo-peaks that would be observed in the detectors. Using the computer code GOSIA it is possible to do the inverse procedure. That is, to figure out what matrix elements are needed in order to get the measured γ-ray intensities. GOSIA takes as an input the detector geometry (angles and distances of the solar cells and the HPGe detectors from the target), the level scheme of the investigated nucleus, all known experimental values such as branching ratios, the γ-yields measured in the experiment and an educated guess for the matrix elements which is used for the initialization of a least-squares minimization procedure. In the end of this procedure, GOSIA gives a full set of the matrix elements and the corresponding chi-square value which indicates the quality

Table 1
In the table below, the measured γ-intensities are compared to the ones calculated from GOSIA using the electromagnetic matrix elements that were extracted from the minimization procedure. The γ-rays are measured by HPGe detectors in two angles, θ=157.6^o and θ=133.57^o. These intensities correspond to γ-rays that are in coincidence with only one solar cell (in this case a solar cell at $\theta = 18^o$) in order to have a well defined recoil angle.

$I_i^\pi \rightarrow I_f^\pi$	$\frac{\text{Exp.Yields}}{\text{GOSIA fit}}$ @ 157.6^o	$\frac{\text{Exp.Yields}}{\text{GOSIA fit}}$ @ 133.57^o
$2_1^+ \rightarrow 0_1^+$	0.96 (0.01)	1.02 (0.01)
$4_1^+ \rightarrow 2_1^+$	0.93 (0.03)	1.06 (0.02)
$6_1^+ \rightarrow 4_1^+$	1.04 (0.12)	0.91 (0.09)
$2_2^+ \rightarrow 2_1^+$	0.87 (0.04)	1.05 (0.03)

of the fit.

One important detail is that the angular distribution of the γ-rays measured in the various Ge detectors is affected by the Fe recoil angle which, therefore, needs to be defined. This is achieved in the off-line analysis of the data by using one solar cell at a time as a condition for the filling of the γ-spectra. In table 1, the γ-yields of the transitions of interest that were calculated by GOSIA for the resulting set of matrix elements are compared to the measured ones when gating on one specific solar cell. As can be observed the agreement is good which indicates the good quality of the fit.

The GOSIA analysis of the data is ongoing (as are some details in the DDCM analysis) and it will hopefully provide the transition strengths of the $2_1^+ \rightarrow 0_1^+$ and the $4_1^+ \rightarrow 2_1^+$ transitions which will serve as a cross-check for the DDCM results, as well as the transition strengths of the $6_1^+ \rightarrow 4_1^+$ and the $2_2^+ \rightarrow 2_1^+$ transitions. Having these numbers at hand, one could then compare these values with the E(5) predictions and either validate ^{130}Xe as an E(5) nucleus or make the E(5) candidates list shorter by one.

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