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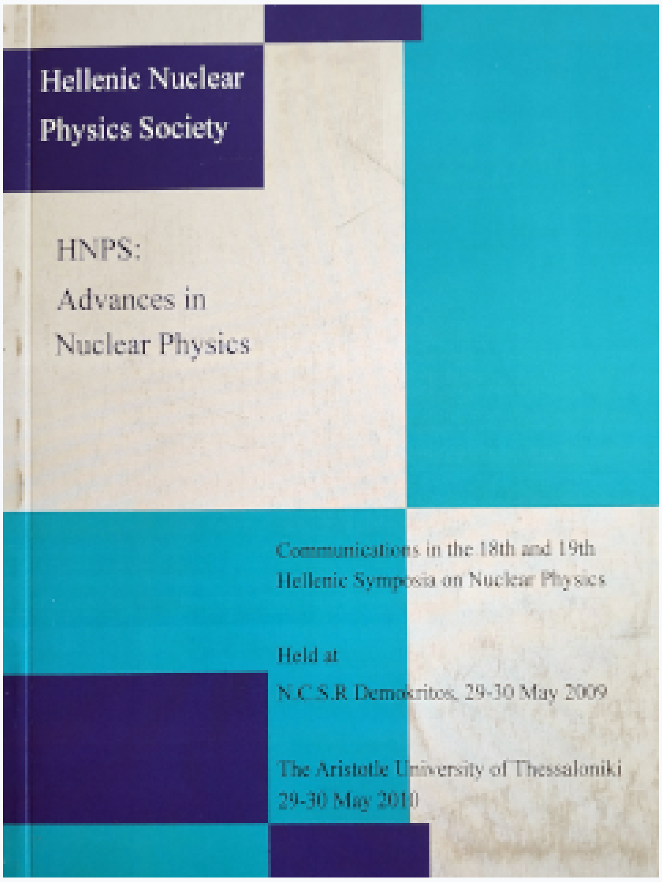

128Xe: Test for E(5) Symmetry through DDCM and GOSIA Analysis

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^{128}Xe: Test for E(5) Symmetry through DDCM and GOSIA Analysis

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Abstract

Lifetime measurements in ^{128}Xe have been undertaken at the JYFL accelerator facility using the novel Coulex-plunger in inverse kinematics technique [1], [2]. Excited states in ^{128}Xe were populated by the ^{nat}Fe(^{128}Xe, ^{128}Xe*) reaction at E(^{128}Xe)=525 MeV and the subsequent de-excitations were detected in the JUROGAM γ-ray array. Two independent analyses of the data were performed. Firstly the Differential Decay Curve Method (DDCM) [3] was applied to determine lifetimes of the excited states. Secondly, matrix elements and their corresponding B(E2) values, were extracted using the computer code GOSIA [4]. The results are presented and compared with the adopted values. Also, B(E2) values obtained from this work are compared to the values predicted by the E(5) critical-point symmetry, since ^{128}Xe has been proposed as a candidate for E(5) symmetry [5].

1. Motivation

The E(5) and X(5) critical point symmetries introduced by F. Iachello [6] describe systems that undergo shape-phase transitions. To date, X(5) symmetry is assumed to be well established [7] whereas this does not fully apply for the case of E(5) symmetry. Under these conditions, the confirmation of the E(5) symmetry in nuclear structure is still an open question motivating further experimental investigation. Among the E(5) candidates proposed, ^{128}Xe and ^{130}Xe have been underlined as two of the most promising ones. Their excitation spectra are indeed in good agreement with those predicted by the E(5) symmetry.

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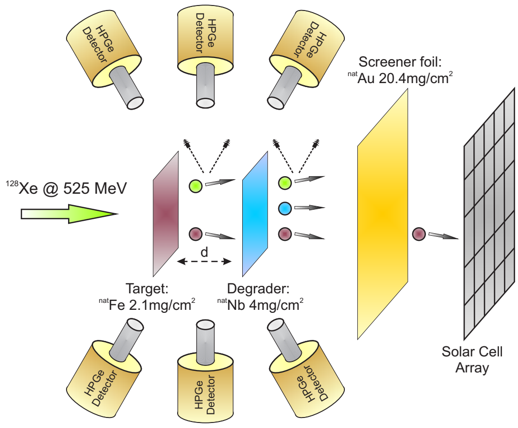

Figure 1: The experimental setup for the Coulex-Plunger technique is shown in the figure. The array of solar cells was placed at the endcap of the beamline covering an angular span between 8^o and 35^o around the beam axis. This allowed the detection of the Fe recoils which gave a clear trigger for the reaction.

A major problem in determining the lifetimes of these nuclei arises from the fact that they cannot be populated in a “standard” plunger experiment, i.e. in a heavy ion induced fusion-evaporation reaction. In addition, as they are in gaseous form they cannot be used as targets. A solution to this problem is Xe-induced Coulomb excitation. In this case, however, the analysis of the measured spectra is often not transparent. The combination of Coulomb excitation with the Recoil-Distance Doppler Shift method, known as Coulex-Plunger technique, has proved to be [8] a powerful experimental approach to determine lifetimes in the pico-second regime, enabling lifetime measurements of yrast as well as non-yrast collective states. The reduced transition probabilities of these states can provide a clear signature of the critical-point symmetry in a nucleus and as such they are of key importance in nuclear structure studies. Applying the Coulex-Plunger technique in inverse kinematics is, from an experimental point of view, a very challenging task not only because of various experimental problems but also because of its possible applicability to lifetime measurements with radioactive ion beams (RIB). On top of confirming the E(5) critical-point symmetry in ^{128}Xe and ^{130}Xe, the increasing interest in RIB worldwide was a strong motivation to perform the present feasibility study of the Coulex-Plunger technique in inverse kinematics.

2. Experimental Setup

The experimental setup is shown in Fig.1. The ^{128}Xe delivered by the Jyväskylä cyclotron with energy of 525 MeV passed through a $2.1mg/cm^2$ Fe foil that served as target. The Coulomb-excited ^{128}Xe nuclei were subsequently retarded by a $4mg/cm^2$ thick Nb foil. The Fe recoils were detected by an array of solar cells arranged at angles between 8^o and 35^o around the beam axis. The setup was surrounded by the JUROGAM array which consists of 45 high purity Ge detectors (HPGe) arranged in six different angles from 157.6^o to 72.05^o with respect to the beam. A screening Au foil was placed

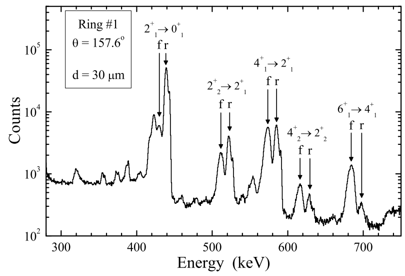

Figure 2: A typical RDDS spectrum is shown. Marked with "f" and "r" are the "flight" and "retarded" component accordingly of each of the five strongest transitions of the Coulomb excited ^{128}Xe. The spectrum is taken at an intermediate plunger distance of 30μm therefore both shifted and unshifted components are clearly visible.

in front of the solar cells. It was $20.4mg/cm^2$ thick in order to stop the Xe and Nb recoils allowing only the Fe nuclei to be detected by the solar cells. The latter recoils served as trigger for Coulomb excited events occurring in the target. This way, particle-γ coincidences between the Fe recoils and the γ-rays depopulating Coulomb-excited states of ^{128}Xe were recorded at 13 plunger distances ranging from 3 to 300 μm. A typical plunger spectrum is shown in Fig.2.

3. Differential Decay Curve Method and GOSIA analysis

The data were first sorted using the code "Grain" [9] and they were subsequently analyzed. Initially, the well known DDCM procedure for the γ-γ-coincidence as well as for the "singles" mode case was applied as described in [3] and [10]. Using this procedure lifetimes were extracted for the first 2^+, 4^+ and 6^+ levels as well as for the second 2^+ as can be seen in figure 3. It must me noted that an independent analysis of the data using the Bateman equations allowed the determination of the 3_1^+ lifetime [11].

As it was mentioned above, the Xe nuclei were excited through the very well known Coulomb interaction thus it is also possible to perform a full Coulomb excitation analysis of the data set by implementing the computer code GOSIA [4]. GOSIA is a least-squares search code, developed to analyze large sets of experimental data in order to determine the electromagnetic matrix elements involved in heavy-ion induced Coulomb excitation. As an input one gives the detector geometry (angles, distances etc.), the level scheme of the investigated nucleus along with any known experimental values such as branching ratios, the γ-yields measured in the experiment and an initial set of matrix elements which serve as a starting point for the minimization procedure. As an output GOSIA gives the full set of the matrix elements and the corresponding chi-square value which indicates the quality of the fit.

One should take notice that for the γ yields measured in the various Ge detectors, the Fe recoil angle 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 trigger for the filling of the γ-spectra. In figure

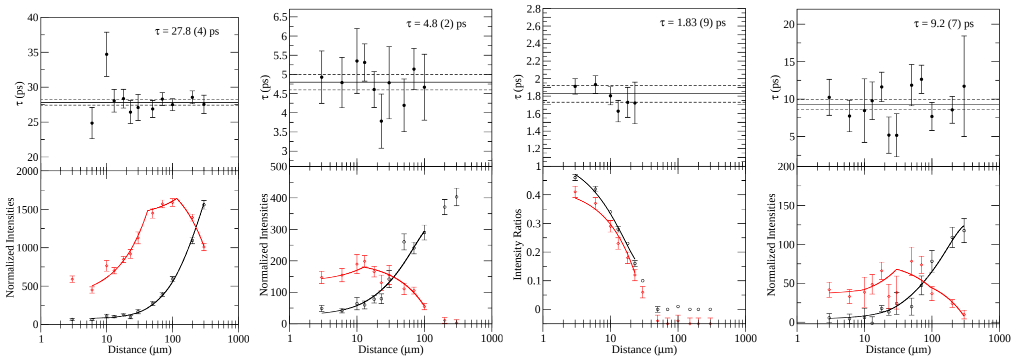

Figure 3: The lifetimes determined through the DDCM analysis for the 2_1^+, 4_1^+, 6_1^+ and 2_2^+ states are shown along with exemplary tauplots. The fitting of the decay curves and the extraction of lifetimes was done with the computer program NAPATAU [12].

4 the γ-yields determined by using three different solar cells as a trigger are shown along with the GOSIA fit.

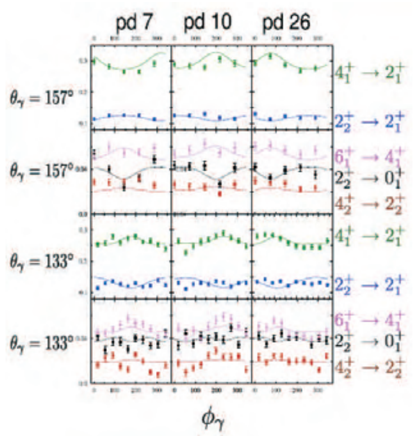

Figure 4: Measured (squares) and fitted (solid lines) γ-intensities for various transitions measured at θ_γ=133^o and θ_γ=157^o in coincidence with the solar cells 7, 10 and 26. Each of the three columns corresponds to the γ-yields measured in coincidence with one solar cell. This way the Fe recoil angle is fixed. The figure is taken from [13].

4. Results and comparison with the E(5) level scheme

The results derived from both analyses procedures, as described above, are summarized in table 1 together with the values given in literature for comparison. Transition strengths for all the involved transitions were calculated either by the lifetimes determined by the DDCM technique or directly from the matrix elements obtained from the

Level	Literature (KK01[14])	Literature (SCK93[15])	DDCM	GOSIA
2_1^+	30.7 (2)	27.0 (3)	28.8 (3)	28.1 (8)
4_1^+	5.0 (4)	5.0 (4)	5.0 (5)	5.0 (3)
6_1^+	1.6 (1)	1.6 (2)	1.8 (1)	1.97 (8)
2_2^+	8.2 (7)	8.4 (8)	8.7 (5)	7.1 (2)
4_2^+	-	3.6 (6)	-	2.1 (16)

Table 1: The lifetimes extracted from this measurement are shown in comparison with the values given in literature. The DDCM values are weighted averages of the lifetimes obtained from the γ-γ-coincident as well as the "singles" data. Good agreement is observed in most cases.

GOSIA analysis. In figure 5 the comparison of the derived experimental B(E2) values with the predictions of the E(5) critical point symmetry clearly shows that ^{128}Xe is not an E(5) nucleus.

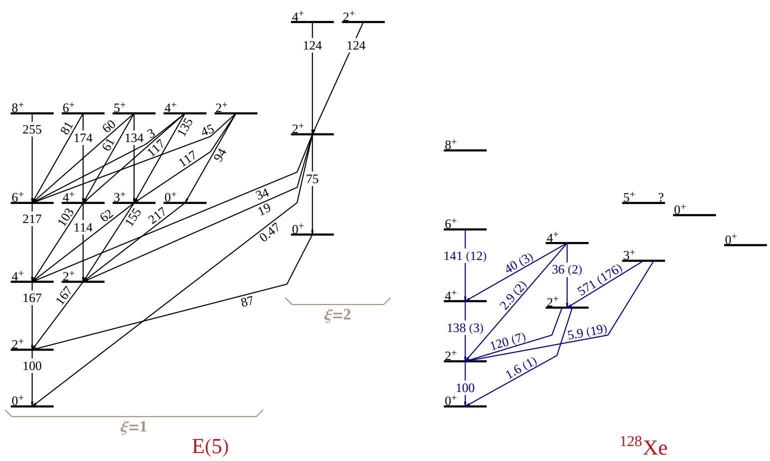

Figure 5: The derived transition strengths for ^{128}Xe are compared to the E(5) predictions. The B(E2) values are all normalized to the $2_1^+ \rightarrow 0_1^+$ transition. It can be seen that although ^{128}Xe does show E(5) features, deviations are apparent thus showing that it is not an E(5) nucleus.

5. Conclusions

Lifetimes of ^{128}Xe were extracted with the implementation of the proposed novel experimental technique named Coulex-Plunger in inverse kinematics. This technique enables a "direct" measurement of the effective lifetimes through the DDCM analysis and an independent determination of the matrix elements of the involved transitions through a Coulomb excitation analysis of the data. The experimental setup is simple and efficient providing us with enough statistics even for the case of the γ-γ-coincidence analysis. Finally, by comparing the derived transition strengths with the ones predicted by the E(5) critical point symmetry it is clearly shown that ^{128}Xe is not an E(5) nucleus.

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