

Projectile Coulomb Excitation of the nucleus ^{194}Pt

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Abstract.

Low-lying collective excited states of ^{194}Pt have been studied via the $^{12}\text{C}(^{194}\text{Pt}, ^{194}\text{Pt}^*)$ projectile Coulomb excitation reaction at 85% of the Coulomb barrier (850 MeV) using the Gammasphere Ge-detector array at Argonne National Laboratory. Absolute $E2$ transition strengths have been obtained from the Coulex cross sections that were deduced from the relative γ -ray yields. They are discussed with respect to the structure suggested by the $O(6)$ symmetry of the Interacting Boson Model.

In nuclear physics, the three dynamical symmetries [1; 2] of the Interacting Boson Model (IBM), $U(5)$ [3], $SU(3)$ [4], and $O(6)$ [5] provide valuable benchmarks for the description of nuclear quadrupole collectivity at low and medium angular momenta. These three symmetries correspond to analytically solvable cases of the Bohr Hamiltonian [6] – the harmonic vibrator, the quadrupole-deformed axial rotor, and the γ -unstable rotor [7].

The $O(6)$ symmetry of the sd-IBM-1 is based on the chain $U(6) \subset O(6) \subset O(5) \subset O(3)$ of nested sub-algebras with quantum numbers N , σ , τ , and L , respectively [1; 2]. The empirical evidence for the existence of nuclei at the $O(6)$ dynamical limit of the IBM is based on energy level patterns, branching ratios and, more convincingly, on selection rules for $E2$ transitions. Within the Consistent Q-Formalism (CQF) [8], they are such that $E2$ transitions are allowed and collective only between states with $\Delta\sigma = 0$ and $\Delta\tau = \pm 1$ [2]. It is the $\Delta\sigma = 0$ selection rule that is definitive of pure $O(6)$ symmetry while the $\Delta\tau = \pm 1$ selection rule actually stems from the $O(5)$ symmetry and is therefore rather ubiquitous for all nuclei between $U(5)$ and $O(6)$ dynamical symmetries. Observation of $O(6)$ symmetry in nuclei has first been reported in the case of ^{196}Pt [9]. This claim was based on energy level patterns and $E2$ decay branching ratios that closely follow the $O(6)$ selection rules. It was, later on, supported by establishing a lower limit for the lifetime of the 0_3^+ state, the lowest state of the $\sigma = N - 2$ representation [10]; the resulting upper limits for the absolute $B(E2)$ values were small, in agreement with the pure $O(6)$ dynamical symmetry [10]. Another, even more extensive region of $O(6)$ -candidate nuclei was found in the Xe-Ba-Ce region [11] around mass number $A = 130$. It has been shown that the low-spin structures of the nuclei ^{128}Xe [12], ^{126}Xe [13] and ^{124}Xe [14] manifest $O(6)$ -like arrangements of energy levels and $E2$ branching ratios which reflect the selection rules for the $\sigma = N$ states of $O(6)$. Lately, the results of new Coulex experiments with the nuclei $^{124,126,128}\text{Xe}$ [15; 16] showed moderate collective character in their respective $0_{\sigma=N-2}^+ \rightarrow 2_{1,2}^+$ transitions, which can be regarded as a severe violation of the $\Delta\sigma = 0$ selection rule. Quantitative analyses showed a complete dissolution of the $O(6)$ symmetry in these nuclei, while the $O(5)$ symmetry is preserved

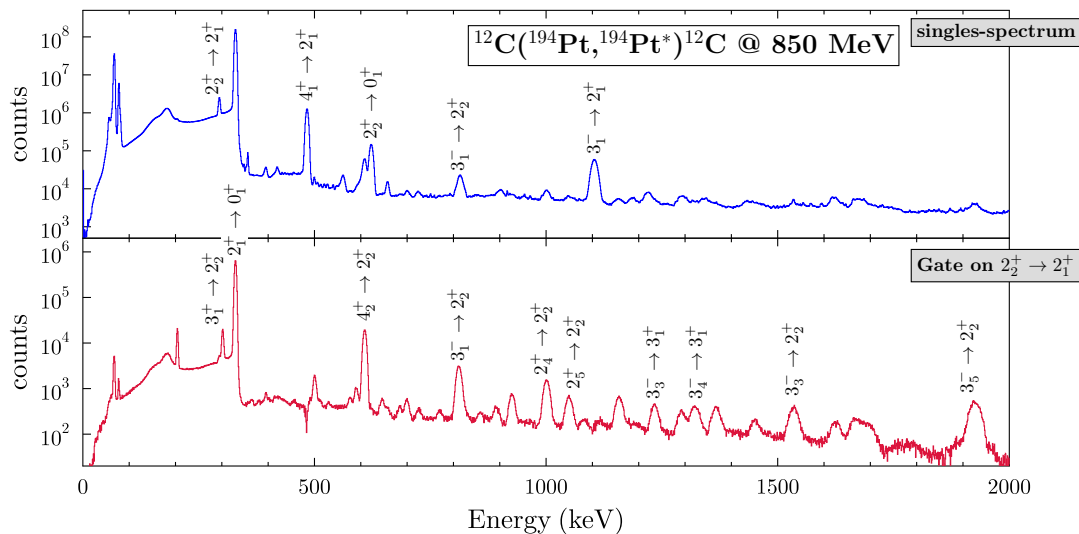


Figure 1. Background subtracted, Doppler-corrected γ -ray spectra of ^{194}Pt after Coulomb excitation on a Carbon target observed with the Gammasphere spectrometer. In the top panel, the sum singles spectrum is shown. In the bottom panel, a spectrum of the γ -rays coincident to the $2_2^+ \rightarrow 2_1^+$ transition is shown. The strongest transitions are indicated.

to a large extent. The amount of symmetry breaking has been quantified by a newly developed analysis of wave-function amplitudes.

In the light of the recent findings it is intriguing to investigate to what extent the $O(6)$ symmetry is preserved or broken in the Pt isotopes. In this work, we report on an experiment of projectile Coulomb excitation of $^{194,196}\text{Pt}$ nuclei, performed in order to study the preservation of the selection rules characteristic for the $O(6)$ symmetry on the basis of the measurement of absolute transition strengths. In the following we will concentrate on the nucleus ^{194}Pt .

The experiment was carried out at Argonne National Laboratory. A pulsed (12 MHz) ^{194}Pt beam was delivered by the ATLAS accelerator. The 850 MeV beam was incident on a 1 mg/cm^2 ^{12}C target. The deexcitation γ -rays, following the Coulomb excitation of the projectile, were detected with the Gammasphere array [17] which consisted of 100 HPGe detectors arranged in 16 rings. In a first run the beam intensity was $\sim 1\text{ pA}$. Gammasphere was used in singles mode resulting in an average counting rate of $1.5 \cdot 10^4$ counts-per-second (cps). A total of $1.6 \cdot 10^9$ events of γ -ray fold 1 or higher was collected in about 28 hours. In a second run, the trigger of the data acquisition was set to a gamma-ray fold of 2 or higher, allowing to increase the beam intensity to $\sim 5\text{ pA}$. The average count rate was $\sim 6 \cdot 10^3$ counts-per-second. In this run, γ -ray coincidence data of $2.3 \cdot 10^8$ events was collected in about 12 hours of beam time. The data from the first run was used to create singles spectra which have been Doppler corrected with respect to the velocity of the recoiling projectile ions of $v/c \approx 8.1\%$. The contribution of the room background was eliminated in the offline sort by correlating the γ -rays with the accelerator radio-frequency (rf) signal. The final spectrum, which is a difference between the ‘beam-on’ (with respect to the rf) spectrum and the ‘beam-off’ spectrum, scaled to eliminate the 1461 keV room background transition from ^{40}K , is shown in the top panel of Figure 1.

The coincidence data from the second run was used to create a $\gamma\gamma$ -coincidence matrix. As an example a spectrum of γ -rays coincident to the transition $2_2^+ \rightarrow 2_1^+$ is shown in the lower panel of Figure 1. A total of 67 transitions could be observed in the coincidence spectra. Due to this large number of observed transitions, only the coincidence data allowed the reconstruction of the level scheme from the observed γ -rays. A part of the deduced level scheme is shown in

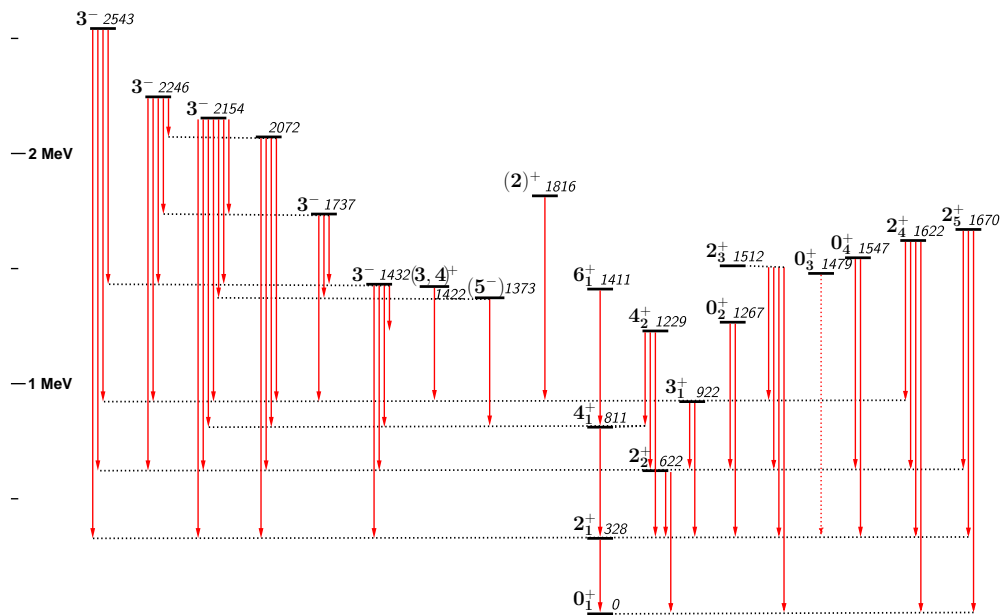


Figure 2. Part of the deduced level scheme of ^{194}Pt together with the placements of some of the γ -ray transitions observed in our experiment.

Figure 2.

All observed γ rays originate from ^{194}Pt nuclei. Many of these γ rays have already been identified in ^{194}Pt [18]. Some transitions, however, have not been reported so far, e.g. the transitions depopulating a state at an excitation energy of 2072 keV and the transitions depopulating the 3^- states at excitation energies of 2145 keV, 2246 keV and 2543 keV. These states have previously been observed in (p, p') reactions only [19; 20].

Efficiency-corrected transition intensities were determined in the singles spectrum where possible. For most of the transitions, the intensity had to be determined from the coincidence data, using transitions visible both in the singles spectrum and in the coincidence data for normalization. The transition intensities were then used to calculate Coulomb-excitation yields, normalized to the yield of the state 2_1^+ at 328 keV. These relative Coulex yields are proportional to the relative Coulex cross sections.

At this stage of our analysis, the relative Coulomb excitation yields of 11 states have been fitted to the Winther-de Boer theory [21] using a multiple CE code [22] and taking into account the energy loss of the beam in the target which can be estimated to about 142 MeV from a Bethe-Bloch approach. The matrix elements involved in the calculations were constrained to the experimental branching ratios and multipole mixing ratios. Adopted quadrupole moments [18] for the states 2_1^+ , 2_2^+ and 4_1^+ were included into the calculation. The quadrupole moments of the remaining states have been varied within the values of the rotational limit, contributing on average by $\sim 4\%$ to the uncertainties of the results. An additional degree of freedom in the Coulex calculation is introduced by the choice of the signs of transition matrix elements. In the case of states with more than one possible excitation path, different combinations of the signs for the transition matrix elements involved in the excitation lead to an increase in the uncertainty of additional 10 – 20% or to ambiguous results beyond their respective uncertainties, like in the case of the state 0_2^+ at 1267 keV. The scale for the calculation is set by the strength of the transition of the state 2_1^+ to the ground state of $B(E2; 2_1^+ \rightarrow 0_1^+) = 49.2(8)$ W.u. [18].

The calculations resulted in 23 absolute $E2$ transition strengths. The strengths of the

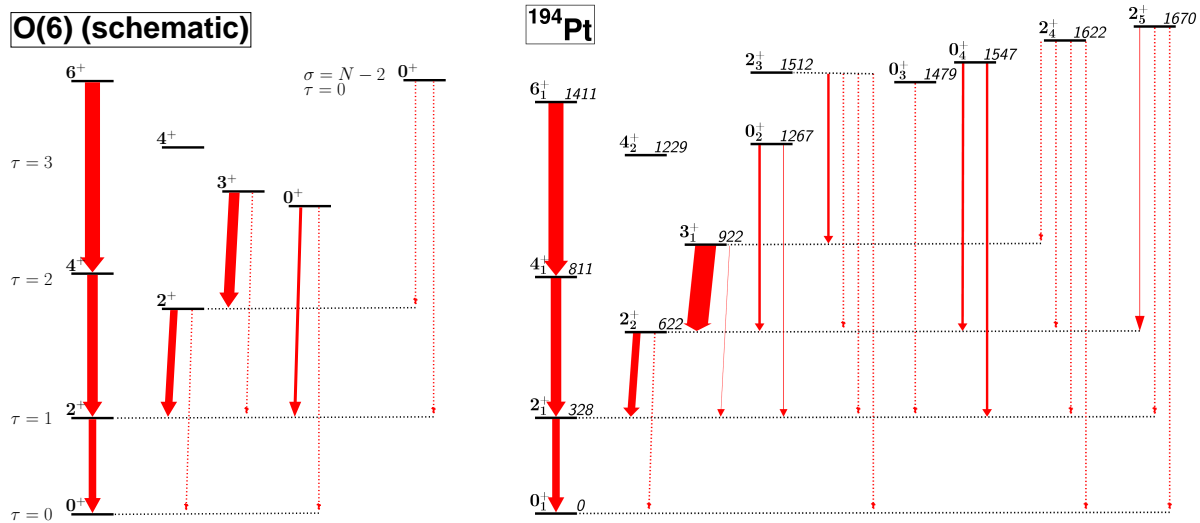


Figure 3. Part of the level scheme, for which transition strengths have been deduced compared to a schematic O(6) level scheme. The widths of the arrows indicating $E2$ decay transitions are proportional to their $B(E2)$ values deduced from our experiment. For $B(E2) < 1$ W.u. we use dashed lines. Decay transitions of the bandhead of the $\sigma = N - 2$ group to the $2_{1,2}^+$ states are forbidden in the O(6) limit. In ^{194}Pt , a clear assignment of the $\sigma = N - 2, \tau = 0$ state is difficult due to the existence of two close-lying 0^+ states in the energy range in question.

transitions depopulating the state 3_1^+ at 922 keV, and the $2_{3,4,5}^+$ -states at 1512 keV, 1622 keV and 1670 keV, respectively, could be deduced for the first time. The resulting strengths of the transitions depopulating the 0_2^+ state at 1267 keV are very sensitive to the choice of the signs of the transition matrix elements involved in the excitation process. Two different possible solutions have been found. At an excitation energy of 1479 keV a 0^+ state is reported, e.g. from beta decay studies [23; 24]. Transitions depopulating this state 0_3^+ could not be observed directly in our data. An estimate of an upper limit for the intensity of the transition to the state 2_1^+ was made from which a small, non-collective upper limit for the value of $B(E2; 0_3^+ \rightarrow 2_1^+)$ could be deduced.

In terms of the selection rules of the O(6) symmetry, a clear conclusion cannot be drawn. The $\Delta\tau = \pm 1$ selection rule is satisfied for transitions depopulating the states 2_2^+ , 3_1^+ , 0_2^+ and 2_3^+ if the τ quantum numbers are assigned to these states according to the typical O(6) scheme [5]. The more difficult question is whether the $\Delta\sigma = 0$ selection rule is preserved. To address this question, one first has to identify states belonging to a representation with different σ quantum number than the yrast states. The most promising candidate to study is the 0^+ bandhead of the $\sigma = N - 2$ family (cf [15]), which will only be populated strongly in the case of a broken O(6) symmetry. In the neighbouring nucleus ^{196}Pt , showing a very similar level scheme to ^{194}Pt , this has been identified as the 0^+ state at an excitation energy of 1403 keV. Considering the level scheme of ^{194}Pt in a similar energy range, one finds two close-lying 0^+ states at energies of 1479 keV and 1547 keV [18]. Under the assumption that the state 0_3^+ can be identified as the $\sigma = N - 2, \tau = 0$ state, the deduced non-collective strength of $B(E2; 0_3^+ \rightarrow 2_1^+)$ would imply a preservation of the $\Delta\sigma = 0$ selection rule. In that case, however, the existence of a close-lying 0_4^+ state with collective $E2$ transitions to the $2_{1,2}^+$ states cannot be accommodated in the O(6) symmetry scheme. If, on the other hand, one assumes the 0_4^+ state to be identified as the state in question, then the collectivity of its decay transitions to the $2_{1,2}^+$ states would imply a severe

breaking of O(6) selection rules, similar to the situation observed in the Xe isotopes [15; 16]. In either case, the existence of two 0^+ states lying that close in energy cannot be described easily using an IBM-1 model close to the O(6) limit. In fact, their very different transition strengths show, that these two states do not mix and hence have a different character. So the question of the nature of the two $0_{3,4}^+$ states in ^{194}Pt remains to be solved.

In summary, a Coulex experiment on the nucleus ^{194}Pt has been performed. In the analysis new information on transition strengths in this nucleus could be deduced. An interpretation of the results against the background of the O(6) selection rules is difficult due to the unresolved nature of the two close-lying 0^+ states around 1.5 MeV.

Acknowledgements

This work has been funded by the DFG under grant Pi 393/2-2, by the DAAD, and by the Alexander von Humboldt foundation

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