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TESTING OF THE BRINK–AXEL HYPOTHESIS WITH THE HECTOR+PARIS+KRATTA SET-UP*

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A very first experiment in the field of nuclear structure at the Cyclotron Centre Bronowice (CCB) facility in Kraków, Poland has been performed recently. The medical cyclotron IBA Proteus C-235 located at CCB produces proton beams in the energy range of 70–230 MeV, that can be used for experimental purposes as well. In the reported measurement, the energy of scattered protons at the incident beam energy of 85 MeV and emitted γ rays from the excited ^{208}Pb target were measured in coincidence. During the experiment excitations in the energy region of the Giant Quadrupole and Dipole Resonances, as well as the Pygmy Dipole States were observed. By applying different conditions on the data, spectra corresponding to γ decays of excited states to selected low-lying levels in ^{208}Pb were obtained, allowing a look into the Brink–Axel hypothesis.

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1. Introduction

Giant Resonances are high-energy collective states of the nucleus, characterised by a large excitation cross section. Of special interest is the Giant Dipole Resonance (GDR), which is interpreted as protons and neutrons out-of-phase oscillation. This excitation mode is induced by E1 transitions and thus is strongly excited in reactions with γ rays. Other prominent E1 excitation mode is the so-called Pygmy Dipole Resonance (PDR), which nature is still a subject of discussion [1–4]. These two modes are responsible, in the wide range of γ energies, for the shape of the gamma-ray strength function (γSF), which describes, within the concept of the statistical model, the average probability of the absorption and emission of γ rays by the nucleus.

The Brink–Axel hypothesis, introduced in 1955 [5], states in its primary form that the GDR can be built on any excited state. Later on, the generalised Brink–Axel hypothesis (gBA) was formulated, proposing that indeed the γSF is independent of energy and spin of the state for which the γSF is measured. This hypothesis forms a basis for (n,γ) cross-section calculations, which, in turn, are used to model the r-process in nucleosynthesis, and thus explain abundances of isotopes observed in the Universe.

There have been several attempts to study gBA, both experimentally and basing on theoretical calculations. Most notably, with the use of the Oslo method, the experimentally obtained γSFs seem to be in agreement with gBA [6]. On the other hand, the results from the ^{208}Pb(p,p') experiment at RCNP in Osaka are inconclusive [7, 8].

2. Experiment

The experimental set-up (Fig. 1) consisted of the HECTOR [9] and KRATTA [10] arrays for the γ-ray and proton energy measurement, respectively [11]. The HECTOR array was positioned at the backward angle of 127° in respect to the beam direction and covered a solid angle of 1.04 sr. Additionally, for a part of the measurement, a cluster of γ detectors of the PARIS array [12] was positioned at 90°, covering a solid angle of 0.24 sr. In order to reduce the elastic scattering background, KRATTA detectors placed at angles 8.9°, 10.7°, 12.5° and 14.3° were used. The total solid angle covered by these detectors was equal to 15 msr. At the fronts of the KRATTA detectors, thin plastic scintillators were positioned, allowing a production of a precise trigger signal.

A self-supporting, 48 μm thick, lead target, enriched to 99.98% in ^{208}Pb was used. The target was irradiated by a proton beam of 85 MeV. The data were collected in the coincidence mode, with signal detection in at least one γ detector and at least one plastic scintillator acting as the triggering condition. The data acquisition was based on both analogue and digital modules which were combined with the use of Multi-Branch System [13]. For the near-line analysis, GREWARE [14] software was employed.

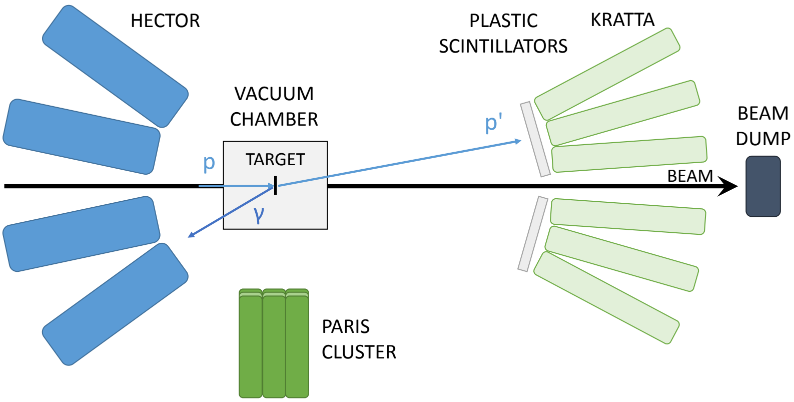

Fig. 1. A schematic view of the experimental set-up.

3. Results

The processed data were collected in correlation matrices of detected γ-ray energy *versus* excitation energy, in which the latter was deduced from the measured energy of an inelastically scattered proton. The final matrix built from the data collected by the HECTOR and KRATTA arrays is presented in figure 2 (a), along with the graphical representation of the conditions used to choose events of the γ decay to the ground state and selected low-lying states.

The condition was defined as $E_\gamma + 0.5 \geqslant E^* - E_i \geqslant E_\gamma - 1$ MeV, where E_i stands for the energy of an excited state. The width of 1.5 MeV comes from the energy resolution of the used arrays and an extra width of 0.5 MeV by which it was broadened to enable addition of the events in which instead of full energy absorption, a single escape of a 511 keV γ ray from a HECTOR detector occurred.

Figure 2 (b) presents a γ spectrum corresponding to the γ decay to the ground state measured by the HECTOR array. In the low-energy part of the spectrum, two peaks are observed, recognised as the g.s. decay of strongly populated 3^- and 2^+ states at $E_{3^-} = 2.6$ MeV and $E_{2^+} = 4.1$ MeV. In the higher energy region, structures in the energy range of the PDR and the GDR are visible. Between these two structures, an excess of counts in the region of the Giant Quadrupole Resonance (GQR) is also evident.

To confirm the observation of the PDR, the γ-ray spectrum of the decay to the g.s. obtained with the PARIS cluster (Fig. 3 (a)) was compared

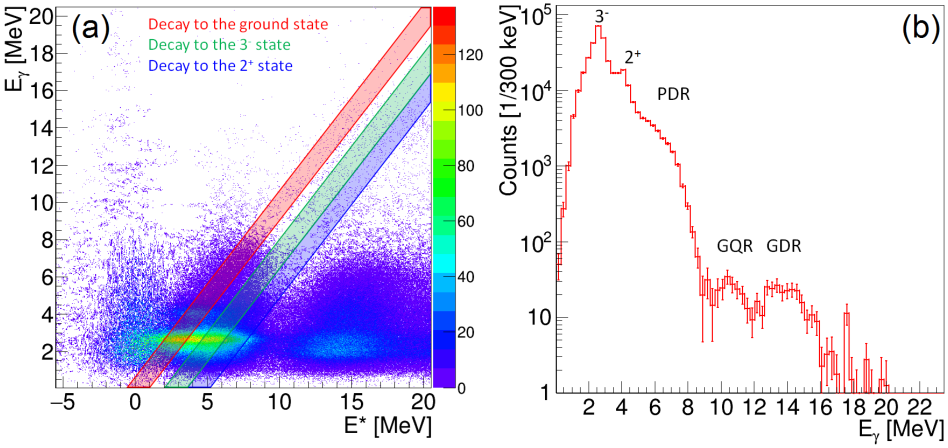

Fig. 2. (a): An E_γ *vs.* E^* matrix measured with the HECTOR and KRATTA arrays. (b): A γ-energy spectrum of the decay to the g.s. measured with HECTOR. The energy regions of discrete low-lying transitions and giant resonances are marked.

with the spectrum from the ^{208}Pb(^{17}O, ^{17}O$'\gamma$) reaction measured with the AGATA array [15]. In the spectrum from the experiment reported here, the most prominent peaks seen in [15] at the energies 5.5 MeV and 6.2 MeV are also visible. The spectrum suffers, though, from low statistics and high Compton background. Because of that, other observed peaks cannot be identified. The overall shape of the spectrum supports the assumption of the PDR observation.

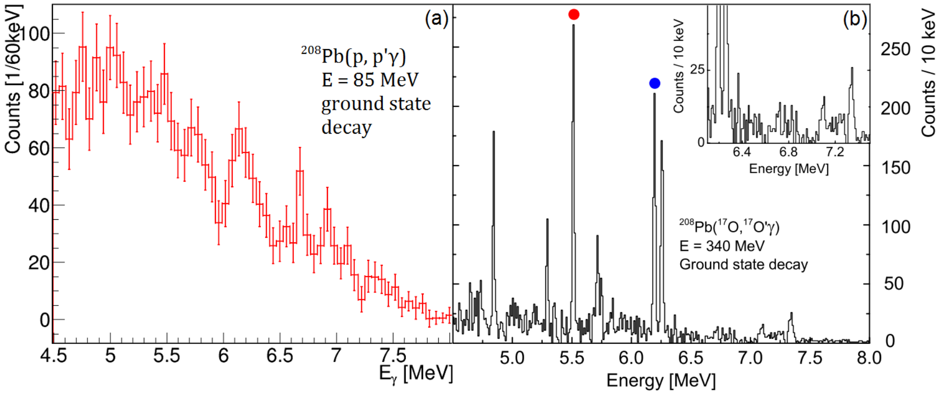

Fig. 3. A γ-ray spectrum corresponding to the decay to the ground state measured in ^{208}Pb($p,p'\gamma$) reaction with the use of a PARIS cluster (a) and in ^{208}Pb(^{17}O, ^{17}O$'\gamma$) reaction with the use of the AGATA demonstrator (b) in the PDR energy region [15].

Decays of the excited nucleus to three different final states were investigated. Besides the decay to the ground state, the decays to the 3_1^- and 2_1^+ levels in ^{208}Pb were studied. The γ-ray and excitation-energy spectra, obtained for all measured cases, are shown in figure 4. The spectra corresponding to the decay to excited states were scaled down by a factor of 10 and 100 for the 3_1^- and 2_1^+ states, respectively.

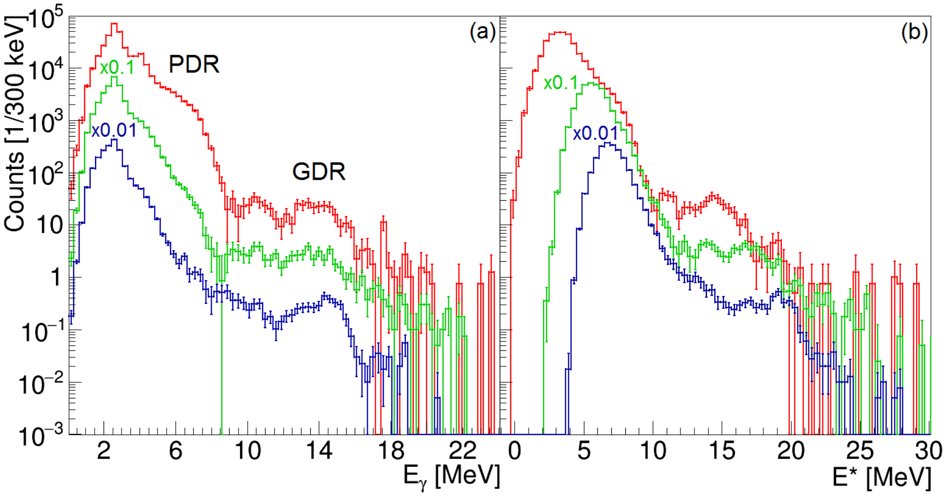

Fig. 4. Spectra of γ-ray energy (a) and excitation energy (b) projected for events of γ decay to the ground state (grey/red), 3_1^- state (light grey/green) and 2_1^+ state (black/blue). Spectra corresponding to the decay to 3_1^- and 2_1^+ levels were scaled down by a factor of 10 and 100, respectively. The energy regions of the PDR and the GDR are marked.

In the energy range of 12–17 MeV, a structure, which can be described by parameters measured for the GDR built on the g.s., is clearly visible in all γ-ray energy spectra. In the excitation-energy spectra gated on the decay to the 3_1^- and 2_1^+ states, a shift of the structures towards higher energy, commensurate with the excitation energy of the final states, is observed. This observation can be interpreted as excitation of the GDR built on the 0^+ (ground state), 3_1^- and 2_1^+ states, supporting the Brink–Axel hypothesis. Additional counts in the higher energy part of this structure in the spectrum related to the decay to the 2_1^+ state can be understood as the decay of the High Energy Octupole Resonance via E1 transition.

Contrary to the GDR energy region, in the case of the PDR, a structure rising above an exponential line is visible in the spectrum corresponding to the decay to the g.s. only. The absence of the PDR in the spectra related to the decay to the 3_1^- and 2_1^+ states seems to be inconsistent with the generalised Brink–Axel hypothesis. In other words, it suggests that gBA does not hold for the PDR states in ^{208}Pb, which are not collective in the sense of involving all nucleons of the nucleus, a requirement for gBA.

This observation could possibly be further explained by the so-called *blocking effect*. In that interpretation, some orbitals are already used in the 3^-_1 or 2^+_1 state configurations and cannot be engaged to build upon them other states of low collectivity, such as the PDR.

The obtained results concerning the generalised Brink–Axel hypothesis need to be verified. Therefore, future similar experiments are necessary to be performed.

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