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Colloquia: COMEX7

Ground-breaking developments in ^{10}B with inelastic proton scattering

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Summary. — We performed an experiment to measure weak γ-decay branching ratios and study angular distributions of γ-decay transitions in ^{10}B for constraining *ab initio* calculations at the 9 MV Tandem accelerator of the Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH). In the experiment, large-volume $LaBr_3$:Ce and $CeBr_3$ scintillators having sufficient efficiency for high energy γ rays were used. In this paper, we present γ-ray intensities obtained from single γ-decay spectra emitted in the $^{10}B(p,p'\gamma)^{10}B^*$ reaction at 8.5 MeV.

1. – Introduction

Our understanding of nuclei has been deepened by a new generation of *ab initio* calculations based on two-, three- and higher multi-nucleon interactions derived from chiral effective field theories (EFT), for a recent review, see ref. [1]. With the advance in *ab initio* many-body theories, there is renewed interest in spectroscopy of the lightest

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doubly-odd $N = Z$ nuclei, as reviewed recently [2]. One of the light-stable doubly-odd nuclei with equal numbers of protons and neutrons ($N = Z$), so-called self-conjugate nuclei, is ^{10}B. In a recent theoretical study, many features such as energy spectra, electromagnetic properties, and point-proton radii of $^{10-14}$B isotopes have been successfully reproduced within the *ab initio* no-core shell model (NCSM) [3]. A number of experiments with different reactions have been performed to measure the γ-decay branching ratios of the ^{10}B, as documented in ref. [4] and references therein. The γ-ray intensities of weak transitions were either not observed, *e.g.*, the tentative ($M3$) transition between the $T = 1$, 0^+_1, 1740.0-keV isomeric analog state (IAS) and the $T = 0$, 3^+_1 ground state which was suggested in the electron scattering experiments [5, 6], or only upper limits were reported, as in the case of $E2$ transitions, *e.g.*, the 1846.7-keV transition between the $T = 0$, 2^+_1, 3587.13-keV state and the IAS [7-11], and the $T = 1$, 2^+_2, 5163.9-keV state and the IAS [11-16]. The 1740.0-keV and 1846.7-keV transitions are expected to be very weak because of the competition with the $M1$ transition, or the isospin change, respectively. Recently, the most precise value of the 3423.1 keV $E2$ partial γ-decay branch has been reported in ref. [11]. This is achieved by taking advantage of the advances in the performance of the detector systems. However, all those measurements were not sufficient to constrain the *ab initio* calculations because of the reported large uncertainties. This requires new and precise measurements of these transitions. Here we will report on a new measurement, performed at IFIN-HH, in the quest for the weakest γ-ray branches in ^{10}B.

2. – Experimental details, data analysis, and results

In our experiment, excited states of ^{10}B were populated by $(p, p'\gamma)$ inelastic scattering reaction with a proton beam at an energy of 8.5 MeV and intensity of 0.8 nA, which was delivered from the 9 MV Tandem accelerator facility at IFIN-HH. An enriched 30 mg/cm^2 thick ^{10}B target was used. The γ rays were detected by 23 of the Extreme Light Infrastructure-Nuclear Physics (ELI-NP) large volume $LaBr_3$:Ce and $CeBr_3$ scintillator detectors from ELIGANT-GN [17] placed inside the bismuth germanate (BGO) anti-Compton active shields of ROSPHERE array [18], realizing a unique array for measurement of high-energy transitions. This arrangement offers users a unique detector array with superior capabilities, such as excellent timing, improved background rejection at high efficiencies. Front collimators were mounted to the BGO detectors to reduce the total count rate in the BGO detectors. However, this configuration reduced the efficiency of the setup by around 50% at low energy. BGO rejection was applied in the digital data acquisition (DAQ) hardware to improve the peak-to-total ratio of the setup. The experimental data were collected with a dedicated DAQ system Digital ELI List-mode Acquisition (DELILA) which was developed in-house at ELI-NP [19]. DELILA controlled CAEN digitizers of type V1730 featuring 16 channels per board with DPP-PSD firmware for the signals of the scintillator and V1725 with DPP-PHA firmware for the signals of HPGe detectors. Each channel had a sampling frequency of 500 MS/s and 250 MS/s for V1730 and V1725 model digitizers, respectively, and used a 14-bit resolution. Data were collected in self-trigging mode. The total trigger rate was around between 800 kHz and 950 kHz. More detailed information related to the experimental setup can be found in ref. [20].

The data were sorted in event-by-event mode and analyzed using the ROOT framework [21]. The matrix of γ-γ coincidence events measured with the scintillators within a 5 ns coincidence gate is shown in fig. 1. The crossing points of the strongest lines of

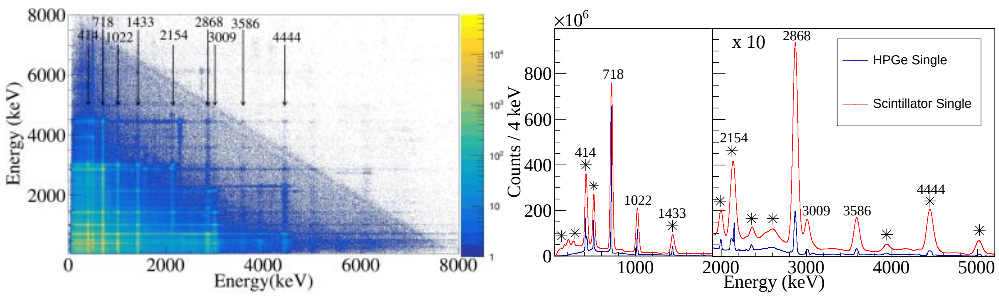

Fig. 1. – (Left) The matrix of γ-γ coincidence events. (Right) Typical LaBr$_3$:Ce, CeBr$_3$, and HPGe single γ-ray energy spectrum. All the γ rays of ^{10}B are indicated by numbers. The asterisks indicate the γ rays from contamination reactions.

^{10}B are marked. An example of a typical single γ-ray energy spectrum obtained during the experiment is shown in fig. 1. The scintillator spectrum is corrected by simulated efficiency which is reported in ref. [20], while the HPGe spectrum is scaled one hundred times for visibility. All the intense transitions are also marked. Several excited states of ^{10}B and some γ-rays from contamination reactions are observed. The measured efficiency-corrected γ-ray intensities which are obtained from single γ-ray energy spectra are presented by assuming 10% systematic uncertainty in table I. The efficiency-corrected γ-ray intensities, I_γ, are normalized to the 718.380-keV transition and compared with the only reported literature values [7]. Large discrepancies are observed between the two data sets. The resulting γ-ray branching ratio for the γ-ray transitions de-exciting the 2154-keV level in ^{10}B is presented and compared in table II with the most recent data in ref. [11]. Although the values are much closer or agree within the uncertainties in this case, some discrepancies remain. Detailed analysis of the coincidence data needs still to be performed.

Table I. – *The energies of γ-ray transitions, E_γ, obtained from a singles γ-decay spectrum of ^{10}B. The efficiency-corrected γ-ray intensities, I_γ, are in %.*

E_γ(keV)	I_γ(%)	Ref. [7](%)
414.1	45.9(7)	-
718.380	100(1)	-
1021.7	32.6(7)	-
1432.7+1435.8	17.7(6)	16(4)
2154.1	10.5(5)	-
2868.3	25.8(8)	44(8)
3009.1	2.03(39)	-
3586.4	5.12(41)	16(4)
4444.4	7.0(5)	11(3)

Table II. – *Branching ratio of the γ-decay transitions for the 2154-keV state in ^{10}B. The uncertainties reported in ref.* [11] *include just statistical uncertainties.*

E_γ(keV)	Present work(%)	Ref. [11](%)
414.1	62.3(7)	57.7(6)
1436	23.9(12)	24.8(5)
2154	13.8(31)	17.5(4)

3. – Conclusion and discussion

The results demonstrate the powerful capabilities of the current unique large-volume scintillator setup. In this experiment, the branching ratio of the γ-decay transitions for the 2154-keV state in ^{10}B is obtained from the single γ-ray spectra. When they were compared with the latest available data, they yielded similar results. Once the final results of the weak γ-decay branching ratios are obtained, the results will be compared with the *ab-initio* calculations in order to determine the role of many-nucleon forces in the nuclear interaction in this system. The next step in the analysis will be to perform angular distributions of γ-decay transitions in ^{10}B.

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