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First Measurement of the $B(E2; 3/2^- \to 1/2^-)$ in ^{7}Be

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Abstract. Ab-initio calculations have been able to reproduce emergent phenomena such as the formation of clusters in nuclei, a prominent feature in light nuclei. A number of ab-initio methods have made predictions for the $B(E2; 3/2^- \to 1/2^-)$ transition strength in the radioactive nucleus ^{7}Be where a prominent α-^{3}He structure is expected. In order to test and guide these ab-inito methods, we have performed a Coulomb excitation experiment to measure the $B(E2; 3/2^- \to 1/2^-)$ in ^{7}Be. Our current results point to the importance of reproducing cluster features in our nuclear models.

INTRODUCTION

A number of ab-initio methods such as No-Core Shell Model (NCSM) and Green's Function Monte Carlo (GFMC) have been used to describe light nuclei. These methods have now been able to reproduce emergent and collective phenomena in nuclei including rotational bands [1, 2] and clustering [3, 4]. These phenomena affect nuclear observables such as electromagnetic moments, charge radii, and transition strengths. By comparing the results of the ab-initio calculations to measurements of these properties, we can understand the important physical aspects of these calculations, which can guide future theoretical work.

Several calculations using ab-initio methods have been performed for $A = 7$ nuclei, namely ^{7}Li and ^{7}Be [5, 3, 6, 7, 8, 9]. The electromagnetic transition strengths between the one bound excited state and the ground state have been calculated by NCSM and GFMC. The experimentally measured $M1$ and $E2$ transition strengths agree with theoretical values, but the $B(E2; 3/2^- \to 1/2^-)$ transition strength of ^{7}Be has never been measured. The measurement of this transition strength will be an important constraint for these ab-initio theories due to the importance of the cluster structure's effect on it. In order to provide this salient constraint, we have performed a Coulomb excitation experiment using a radioactive beam of ^{7}Be to measure the $B(E2; 3/2^- \to 1/2^-)$ transition strength of ^{7}Be.

EXPERIMENT AND ANALYSIS

We have perfomed a Coulomb excitation experiment using a radioactive beam of ^{7}Be and a natural Au target. The ^{7}Be beam was produced using the *TwinSol* separator [10] at the Nuclear Science Laboratory at the University of Notre Dame. A primary beam of ^{6}Li was accelerated to 34 MeV with the FN Tandem Van de Graaff accelerator and impinged on a gas cell containing deuterium at 1 atm of pressure. The secondary ^{7}Be beam was produced in a $d(^6\mathrm{Li},n)^7$Be reaction and was focused by the dual superconducting solenoids of *TwinSol*. The ^{7}Be beam was 85% pure with the main contaminants being ^{6}Li, ^{7}Li, and ^{4}He. The energy of the ^{7}Be beam was measured to be 30.5 MeV with surface-barrier Si detector upstream of the target. This energy corresponds to 77% of the Coulomb barrier so there were no other open reaction channels. The inelastic excitation from the nuclear interaction is expected to be negligible

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compared to Coulomb excitation at this energy and forward scattering angles. The ^{7}Be beam impinged onto a 1 μm-thick Au foil and the scattered ions were detected in a circular double-sided Si detector (Micron S2 [11]) that was placed downstream of the target. Surrounding the target chamber were six high-purity Ge (HPGe) clover detectors. These were used for detecting γ rays emitted from de-exciting ^{7}Be nuclei. Fig. 1 depicts the target chamber and detector setup. The target chamber was cylindrical and made of aluminum. The geometry and material were chosen to maximize the HPGe detectors' geometrical coverage of the target and minimize γ-ray attenuation, respectively. Signals from the Si and Ge detectors were digitized using a digital data acquisition system sampling the preamplifier waveforms at 100 MHz. A signal from the Si detector was used as a trigger condition and data were written to hard disk in list mode.

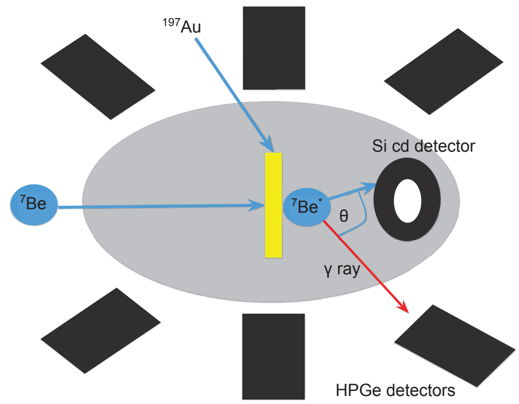

FIGURE 1. A drawing of the target chamber setup used in our Coulomb excitation experiment. The chamber is cylindrical and the HPGe detectors are placed around it on the horizontal plane.

The S2 Si detector was segmented into 24 concentric rings on the upstream side and into 16 sectors on the downstream side. The position information was used to Doppler correct the γ rays that were emitted in-flight. The Si and HPGe timing information was used to subtract random background counts. The Doppler-corrected background-subtracted γ-ray spectrum is shown in Fig. 2. An unambiguous peak can be seen at the expected transition energy of 429 keV. Using the efficiency calibration performed with a standard ^{152}Eu γ source, we were able to measure the γ yield from the Coulomb excited ^{7}Be nuclei. In addition, the ^{7}Be beam rate was deduced from a Geant4 simulation of the elastic scattering where the relatively large beam spot size was taken into account. This beam rate was found to be $8.4(4) \times 10^4$ pps. We used this beam rate from the S2 Si detector and the measured γ yield to deduce the Coulomb excitation cross section to the first excited state.

We used the Coulomb excitation cross section and the ^{7}Be beam rates with the CLX Coulomb excitation code that is based on the Winther and de Boer COULEX program [12] to compute the $B(E2; 3/2^- \rightarrow 1/2^-)$ transition strength. The preliminary value of the transition strength was found to be $B(E2; 3/2^- \rightarrow 1/2^-) = 34(8)$ e^{2}fm^4. We estimate a number of systematic uncertainties that come from the uncertainty in the true distribution of ^{7}Be on the target, contributions from $M1$ excitations in the Coulomb excitation process, and second-order effects such as $E1$ dipole polarizability that comes from virtual break-up excitations. The total contribution of these are estimated to be on the order of 5% or less. Therefore the systematic uncertainty in our result is ±2 e^{2}fm^4 and the total uncertainty is primarily statistical in nature.

RESULTS AND DISCUSSION

We compare our experimental $B(E2; 3/2^- \rightarrow 1/2^-)$ value to several known calculations by ab-initio methods. The values are given in Table 1 and plotted in Fig. 3. It can be seen that the experimental value is larger than both model predictions although consistent considering the measurement's uncertainty. The Green's Function Monte Carlo results are larger and in more agreement with our result. The No-Core Shell Model with cluster wavefunctions added to the

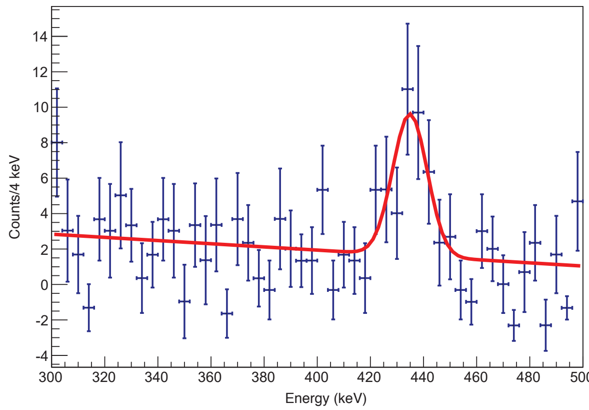

FIGURE 2. The Si-detector-gated Doppler-corrected γ-ray spectrum showing the $3/2^- \rightarrow 1/2^-$ transition at 429 keV.

Hilbert space using the Resonating Group Method [8, 9, 13] is also consistent within 2σ uncertainty, but outside of our 1σ uncertainty. The correlation of these theoretical results to the formation of cluster structure in the calculations can point to the how prominent these cluster components are for the structure of ^{7}Be.

TABLE 1. Calculated $B(E2; 3/2^- \rightarrow 1/2^-)$ transition strengths and our measured value given in e^2fm^4.

	$B(E2; up)$
Experimental	34(8)
GFMC*	27.5(8)
NCSM/RGM†	20.02

* Ref. [6].
† Ref. [8] and [9].

The precision of ab-initio methods have reached a level where meaningful comparisons to experiment and predictions can be made. This first measurement give an additional test and constraint to guide these ab-initio methods. A future higher statistics measurement of the $B(E2; 3/2^- \rightarrow 1/2^-)$ in ^{7}Be can further guide these models.

SUMMARY

We have measured the $B(E2; 3/2^- \rightarrow 1/2^-)$ in ^{7}Be for the first time and have compared our result to presently available theoretical predictions from nuclear models using ab-initio techniques. Our preliminary results shows that the formation of cluster structure in these models are an important part of describing electromagnetic transition strengths. The results of a final analysis and a more detailed comparison to model predictions will be presented in a future publication. Future measurements of transition strengths with higher precision for a number of neighboring unstable nuclei such as ^{8}Li will continue to guide these ab-initio methods.

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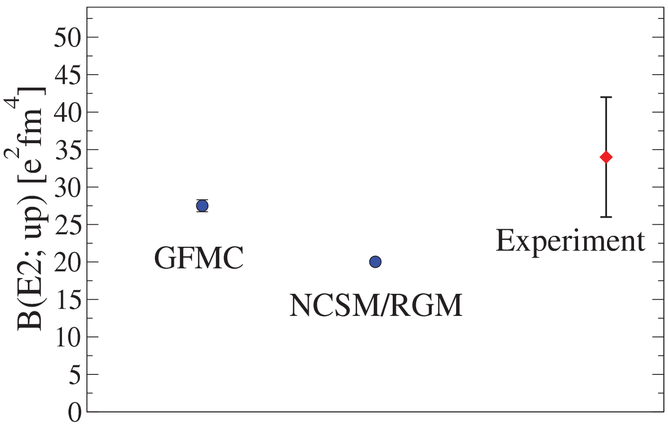

FIGURE 3. Calculated $B(E2; 3/2^- \rightarrow 1/2^-)$ transition strengths compared with our preliminary measured value.

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