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The electromagnetic transition strength between the two bound states were measured in the one-neutron halo nucleus ^{11}Be from Coulomb excitation on ^{196}Pt at projectile energies of 1.727 and 2.086 MeV/nucleon at TRIUMF. A $B(E1)$ strength of 0.102(2) e^2fm^2, deduced from the forward-scattering data, is consistent with previous Coulomb excitation measurements at intermediate projectile energies with a model-dependent analysis.

1. Introduction

In very light nuclei in the vicinity of the neutron drip line, weakly bound systems with extended wave functions known as halo nuclei have been observed and is thought to have a strong influence on the unbound state properties.[1] Strong low-lying $E1$ strengths to the continuum from break-up reactions[2–4] and between the only two bound states in the one-neutron halo nucleus ^{11}Be have been observed. The accuracies of ∼10% and ∼5% for the $B(E1)$ between the bound states and to the continuum of ^{11}Be, respectively, have been measured, but with discrepancies ∼15% between the reported strengths for the latter. The energy wieghted $\Sigma B(E1)$ strength up to 4 MeV was found to exhaust 70(10)% of the cluster sum rule.[4] A reduced transition strength $B(E1)$ of 0.116(12) e^2fm^2 corresponding to 166(15) fs between the first excited state and ground state (g.s.) has been determine by the Doppler-shift attenuation method (DSAM),[5] making it the fastest known electric dipole transition between bound states. Coulomb excitation experiments at intermediate projectile energies,[6–8] with the expectation of Ref.[9] which had a problem with normalization, verified an enhanced transition strength between the bound states with a weighted $B(E1)$ average of 0.105(7).[8] The analysis of the Coulomb excitation experiments at $E(^{11}Be)$ = 60 and 64 MeV/nucleon[6,7] use a semi-classical model which assume that the excitation occurs in a single-step process and does not include corrections due to the continuum and higher order effects, such as nuclear absorption and excitation. A model dependent analysis at 39 and 59 MeV/nucleon[8] using the quantum mechanical reaction code, the extended continuum discretized coupled channels model (XCDCC),[10] indicted that the continuum, nuclear and higher order effects enhance/suppress ∼2-20% of the strength. By lowering the projectile energy, these effects are expected to be minimized.

Two high precision measurements of the $B(E1)$ strength between the bound states in ^{11}Be has been carried out recently at TRIUMF using projectile energies below the Coulomb barrier to improve on the accuracy reported in previous measurements of the $B(E1)$ between the bound states and to resolve the 15% discrepancy to the continuum. Higher accuracy in the electromagnetic properties of ^{11}Be will help resolve the discrepancies of the previous works and will also help isolate the importance of contributions from individual terms of the NN interactions in models that describe halo systems such as the No-Core Shell Model plus Resonating Group Method.[11] In this short communication, results for the $B(E1)$ between the $1/2^+$ g.s. to the 320 keV $1/2^-$ state is presented. The experimental setup and results are discussed in Sec. 2 and the summary is given in Sec. 3.

2. Experiment

The experiments were fielded at TRIUMF's Isotope Separator and Accelerator II. Three ^{11}Be beams with intensities of $>10^6$ ions/second were accelerated to 1.73, 2.09 and 3.82 MeV/nucleon. A 2.92 mg/cm^2 platinum target enriched to 94.57% in ^{196}Pt was used to scatter the ^{11}Be beam into the Bambino array,[12] which consisted of two double sided segmented 140-μm thick Si ΔE detectors. Gamma rays emitted from the excited projectile/target were measured in coincidence with charge particles using 12 high purity germanium clover detectors TIGRESS[13] which encapsulated the Si detectors. Shown in Fig. 1a is the measured γ-ray spectra for the region of interest at incident energy of 2.09 MeV/nucleon in the lab and projectile frames. The transitions between the first excited and g.s. in ^{196}Pt and ^{11}Be are labeled. The Si detectors segmented into 32 sectors and 24 rings for a scattering angle coverage between 18.6°-47.0° and 133.0°-161.4° in the lab frame allowed for a resolution of 1.4% full width at half max for the 320 keV transition in the Doppler-shift corrected spectrum. Events due to scattering of room returns, natural activity and the β decay of ^{11}Be within a 125 ns coincidence gate were subtracted out using events outside the acceptance window corresponding to random background.

The γ-ray yields from the 320 keV state to g.s. in ^{11}Be were examined at ten angles, six in the forward region and four in the back and compared with calculations from the semi-classical code Gosia[14] and XCDCC. Comparison with XCDCC and the $B(E1)$ strength to the continuum will be presented elsewhere. The analysis was constrained to $E(^{11}Be) = 1.73$ and 2.09 MeV/nucleon and to the forward angles to minimize the impact of the break-up reaction mechanisms. The extracted $B(E1)$ value does not include any contribution to the continuum. Preliminary calculations of the cross sections of the 320 keV transition in ^{11}Be from a full quantum calculation using XCDCC indicate that there is little sensitivity and negligible for the forward angle to the continuum. The γ-ray yields from ^{11}Be were normalized to the 355 keV g.s. transition in ^{196}Pt with an adopted $B(E2)$ value of 0.274(1) e^2b^2.[15] The systematic uncertainties in the measurements include corrections for the Rutherford Scattering and for the fitting of the $2^+ \rightarrow 0^+$ transition in ^{196}Pt. An adopted $B(E1)$ value from the current measurements of $0.101(2)e^2$fm^2 was determined from the minimization of χ^2 in accordance to Ref.[16] Shown in Fig.1b is a comparison of the measure yields at 1.727 and 2.086 MeV/nucleon versus the expected yields from Gosia with $B(E1) = 0.101e^2$fm^2. The dashed lines are the yields from

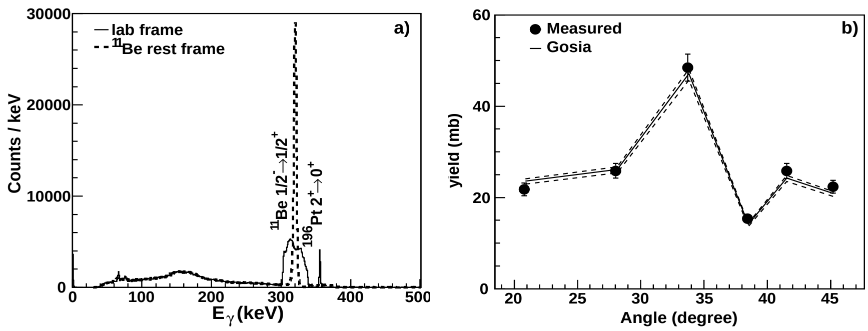

Fig. 1. a) The background subtracted γ spectra at incident energies of 2.086 MeV/nucleon in the lab and projectile frames. b) Comparison of Gosia calculations to the sum experimental yields at 1.727 and 2.086 MeV/nucleon. The dashed lines are calculated yields from Gosia obtained by varying the $B(E1)$ value by $\pm$2%.

Gosia from varying the $B(E1)$ value by $\pm 2\%$. The deduced $B(E1)$ from the current work is consistent with the previous reported values from intermediate energy Coulomb excitation of Refs.[6–8] and is $\sim$12% lower than the reported value from the DSAM measurement.

3. Summary

The transition strengths between the two bound states and to the continuum in ^{11}Be was investigated simultaneously at 1.73, 2.09 and 3.82 MeV/nucleon by Coulomb excitation on ^{196}Pt. A deduced $B(E1)$ value for the transition between the two bound states of 0.101(2) $e^2\mathrm{fm}^2$ from the semi-classical code Gosia is 12% lower than the value from the DSAM experiment and is consistent with the previous Coulomb excitation experiments at intermediate energies using the model-dependent analysis. In addition, the lower projectile energies used in the current work minimized the corrections needed for the higher order effects such as nuclear absorption and excitation and allowed us to obtain higher accuracy. The $B(E1)$ values between the bound states and to the continuum will also be determined using XCDCC and be presented elsewhere.

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