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Resonant scattering measurement for ^{11}C using thick target in inverse kinematics

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Abstract.
The resonant scattering of ^{10}B+p reaction was measured at $\theta_{\rm c.m.}$= 180°, 170°, 160°, 150° and 140° using a 35.93 MeV ^{10}B beam to investigate the spectroscopy of ^{11}C with the thick target inverse kinematic method at RIBRAS facility, IFUSP, São Paulo. Influence of the stopping power uncertainty on the resonant scattering cross section values for ^{11}C in the ^{10}B$(p,p)^{10}$B reaction is shown. The data measured for the reaction channels $p(^{10}$B,$\alpha)$ and $p(^{10}$B,^{3}He) is also presented. Interestingly, the cross sections for the ^{3}He channel are observed upto 2 MeV below the lowest energy measurement available in literature.

1. Introduction

Resonant reactions measured in direct kinematics are among the oldest methods [1] that have allowed extensive studies to establish the low-lying states with well-defined energies, spins, and parities for stable light nuclei. However, many discrepancies exist in the reported values for excitation energies and there is a lack of spin-parity assignment for the resonances in near-threshold systems, in particular, for light nuclei like ^{11}C. A recent low energy experiment in forward kinematics using a proton beam on enriched ^{10}B is reported in Ref. [2], where the most backward angle measured is at θ_{cm}= 170°. A systematic analysis of these data using the R-matrix formalism [3] was recently performed by Wiescher et al. [4], showing two dominant resonances at the E_x = 10.08 (7/2+) and 10.68 (9/2+) MeV in ^{11}C. However, the level density of ^{11}C, above the proton threshold, starts to increase rapidly and the levels are described by large particle widths of the order hundreds of keV. This has made mapping the level scheme of ^{11}C quite challenging and the level properties above E*= 11 MeV are particularly uncertain. The extra data obtained with different mechanism such as inverse kinematics would help to improve the determination of the spectroscopic information on the levels. While the inverse kinematic measurements cannot compete with the classical direct kinematic approach in terms

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of energy resolution, it can provide the systematic excitation functions with better normalization and better extraction of contaminants. Also, resonances may be more pronounced at θ_{cm}= 180° and cannot be measured in forward kinematics approach. Also, this technique carries with it a different set of systematic uncertainties. The resonant elastic scattering for the ^{10}B+p reaction was performed using the Thick Target in Inverse Kinematics (TTIK) technique [5, 6]. The experiment was conducted with the RIBRAS facility at IFUSP [7] and the results for the ^{10}B$(p,p)^{10}$B reaction channel were recently published in ref. [8] along with the R-matrix calculations using the code Azure2 [3].

2. Results and Conclusions

To convert the proton kinetic energy to center of mass energy, the proton energy loss must be correctly considered. In our recent work [8], we used the LISE++ code [9] for the stopping power calculations. Also the cross section is very sensitive to the stopping power. Ref. [10] showed that the uncertainty in the stopping power can be 5% to 20% for light to heavy ions, and can affect the shape of the cross-section. We have investigated the sensitivity of the energy spectra to the stopping power. For this, we performed the analysis with an increase in the value of energy loss calculated
a check on both the E_{lo}
the target after the rea
observed that it has neg

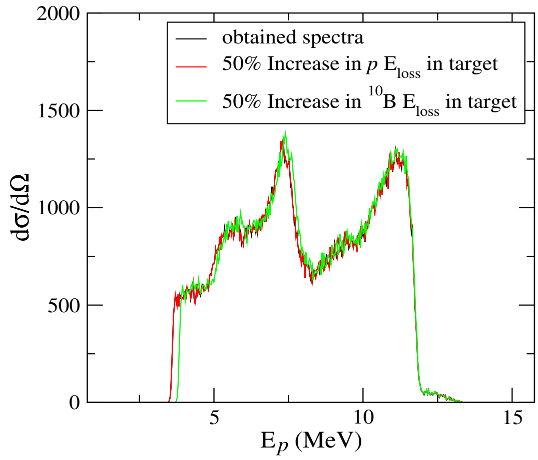

Figure 1. Comparison of spectra measured at θ_{cm}= 180° for different energy losses in target.

In our publication [8], the detailed analysis of the ^{10}B$(p,p)^{10}$B reaction channel was reported. However, besides elastic scattering, other reactions channels such as $p(^{10}\text{B},\alpha)^{7}$Be and $p(^{10}\text{B},^{3}\text{He})^{8}$Be were also measured. The corresponding excitation functions (energy spectra) for these channels are presented in figure 2 and 3, respectively. The reaction Q-values for α and ^{3}He are +1.1457 and -0.5332, respectively.

One of the main advantages of the present measurement, in comparison with backscattering in forward kinematic, is the online beam intensity readout. In the experiment we have used scattered ^{10}B beam impinging on a plastic target. The proportionality of the readout of ^{10}B beam from the Faraday cup and the scattered ^{10}B beam, refocused on the plastic target, was kept practically constant during the experiment. This allows us to precisely measure the intensity of the incident beam, hence, reducing the error in the extracted excitation function. The

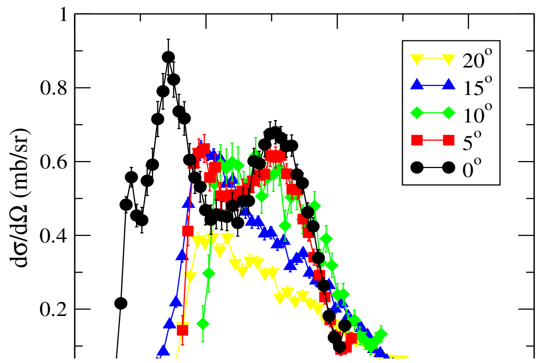

Figure 2. Excitation
angles in inverse kine

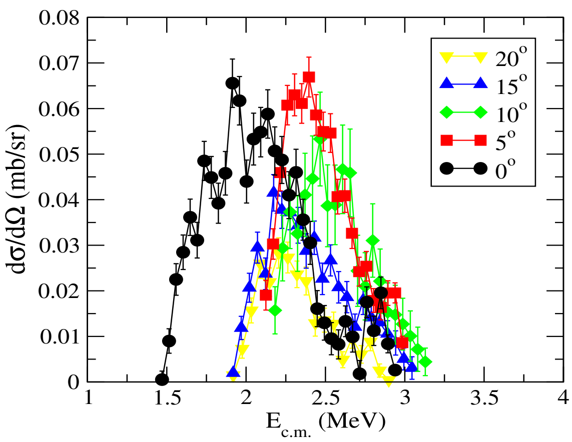

Figure 3. Similar to Figure 2 but for ^{3}He particles from the p(^{10}B,^{3}He)^{8}Be reaction.

background contribution of protons from the reaction of ^{10}B with the carbon nucleus, also present in the plastic target, is perfectly removed through separate measurements with a pure ^{12}C target using the same ^{10}B beam under the same experimental conditions.

The particle threshold for the p(^{10}B,^{3}He)^{8}Be reaction is at $E_p = 590$ keV although in ref. [11] it was observed that the lowest energy measurements do not begin until $E_p \approx 4.0$ MeV. The penetrability arguments, and the lack of experimentally observed lower energy yields, suggest this reaction remains weak up to these higher energies. The (p,^{3}He) reaction has weak resonances in strong contrast to the (p,α) reaction. In the ref. [11], it is also reported that excitation functions do pass through slight maxima at similar energies to those present in the (p,α) reaction.

It is interesting to point that in the present measurement we have observed ^{3}He particles up to 2 MeV, thus below E_p =4.0 MeV (where E_p =4.0 MeV is equal to $E_{c.m.}$ =3.6 MeV). However, there is a shift in the measured spectra at different angles that may be due to uncertainties in energy loss correction for ^{3}He that do not have a well define edge to be considered.

In the near future, we will perform the R-matix calculations for the ^{10}B(p,^{3}He) and ^{10}B(p,α) reactions to extract more information on resonance properties of ^{11}C near threshold.

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References
[1] N. Bohr, Nature 137, 344 (1936).
[2] M. Chiari, L. Giuntini, P. Mandò, and N. Taccetti, Nucl. Instrum. Methods Phys. Res., Sect. B 184, 309 (2001).
[3] R.E. Azuma, E. Uberseder, E.C. Simpson, C.R. Brune, H. Costantini, R.J. deBoer, J. Görres, M. Heil, P.J. LeBlanc, C. Ugalde, and M. Wiescher. Phys. Rev. C 81, 045805 (2010).
[4] M. Wiescher, R. J. DeBoer, J. Gorres, R.E. Azuma, Phys. Rev. 95, 044617 (2017).
[5] K.P. Artemov et al., Sov. J. Nucl. Phys. 52, 406 (1990).
[6] M. Benjelloun, Th. Delbar, W. Galster, P. Leleux, E. Liénard, P. Lipnik, P. Duhamel, J. Vanhorenbeeck, C. Rolfs, G. Roters, H.P. Trautvetter and W. Rodney, Nucl. Ins. and Meth. in Phys. Res. A321, 521-528 (1992).
[7] R. Lichtenthäler, A. Lépine-Szily, V. Guimarães, C. Perego, V. Placco, O. Camargo jr., R. Denke, P.N. de Faria, E.A. Benjamim, N. Added, G.F. Lima, M.S. Hussein, J. Kolata, and A. Arazi, Eur. Phys. J. A 25, s01, 733-736 (2005).
[8] Gurpreet Kaur, V. Guimarães, J.C. Zamora, M. Assunção, J. Alcantara-Nunez, A.L. de Lara, E.O.N. Zevallos, J.B. Ribeiro, R. Lichtenthäler, K.C.C. Pires, O.C.B. Santos, V. Morcelle, R.J. deBoer, Phys. Rev. C 105, 024609 (2022).
[9] M.P. Kuchera, O.B. Tarasov, D. Bazin, B. Sherril, K.V. Tarasova, Nucl. Instr. and Method B 376, 168 (2016).
[10] W.H. Trzaska et al., NIM in Phys. Res. B 418, 1-12 (2018).
[11] J. Jenkin, L. Earwaker, and E. Titterton, Phys. Lett. 4, 142 (1963).