Measurement of ^{20}Ne and ^{16}O ground state α-ANCs

E. Harris,[1,2] M. Barbui,[1] J. Bishop,[1] G. Chubarian,[1] E. Koshchiy,[1] Z. Luo,[1,2] C.E. Parker,[1] M. Roosa,[1,2] A. Saastamoinen,[1] D.P. Scriven[1,2] and G.V. Rogachev[1,2]

[1]*Cyclotron Institute, Texas A&M University, College Station, Texas 77843*

[2]*Department of Physics & Astronomy, Texas A&M University, College Station, Texas 77843*

The Asymptotic Normalization Coefficient (ANC) method is a powerful indirect technique often used in experimental nuclear physics to study stellar radiative capture reactions. This method focuses on determining ANCs of nuclear bound states and resonances, which represent the amplitude of the bound-state wave function in the asymptotic region far from the nuclear interior. These coefficients (C) can be extracted experimentally from the differential cross sections of peripheral transfer reactions using the following equation [1]:

$$\left(\frac{d\sigma}{d\Omega}\right)_{exp} = \frac{\left(C^{A}_{a,x}\right)^2}{b_A^2}\frac{\left(C^{B}_{b,x}\right)^2}{b_B^2}\left(\frac{d\sigma}{d\Omega}\right)_{DWBA} \quad (1)$$

This holds for a direct transfer reaction of A + b → B + a, where A = a + x and B = b + x, with x being the transferred particle. Once determined, these ANCs can then be used for the calculation of astrophysical reaction rates. For example, the rate of the well-known α-capture reaction ^{12}C(α,γ)^{16}O has been further constrained by determining the ANCs of states below the α-decay threshold in ^{16}O. This work aims to determine the ANC of the ^{16}O ground state as it currently contributes to the large overall uncertainty of the ^{12}C(α,γ)^{16}O reaction rate.

For this study, we have chosen the α-transfer reaction of ^{12}C(^{20}Ne,^{16}O)^{16}O populating the ground state of both ^{16}O products. The energy of the beam was chosen such that both the entrance and exit channels of this reaction are (nearly) sub-Coulomb. This technique, pioneered by C. Brune [2], has been shown to minimize model dependence and uncertainties of the resulting ANCs. To further reduce model dependence, we employ a ratio of the transfer cross section to the elastic scattering cross section at large angles in the center-of-mass system. This eliminates dependence of the result on beam geometry, target thickness, and detector efficiency, while also lessening sensitivity to the chosen optical potential.

The ^{12}C(^{20}Ne,^{16}O)^{16}O α-transfer experiment was carried out in June of 2021 using the MDM spectrometer and TexPPAC detector system [3]. A low-energy beam of ^{20}Ne at 1.0 and 1.1 MeV/u was produced by the K150 cyclotron and delivered to the scattering chamber where it impinged on a natural ^{12}C target of 22 μg/cm^2 thickness. The ^{16}O reaction products were magnetically filtered through the MDM at an angle of 5° and 15°, and were then detected in the TexPPAC focal plane detector. The position along the X-plane of the detector along with time-of-flight (TOF) between PPACs was used for particle identification of ^{16}O. Utilizing the ^{16}O charge-state fraction determined previously [4], and the number of background-subtracted counts of ^{16}O in TexPPAC, the differential cross section of the α-transfer reaction was determined. The calculation of single-particle ANCs and theoretical cross section were performed using Distorted Wave Born Approximation (DWBA) with the code FRESCO. Equation 1 was then used to determine the ANCs. Because neither the ^{16}O nor ^{20}Ne ground state α-ANCs are known independently, the final experimental result of this work is the product of the two ANCs.

In addition to our experimental result, three independent theoretical calculations of the ANC product were performed by groups from Louisiana State University, Michigan State University, and Florida State University. All participants were tasked with calculating the product of the ground state α-ANCs of ^{20}Ne and ^{16}O. The three competing theoretical methods applied in this study are the Configuration Interaction Model [5], the No-Core Shell Model [6], and the Lattice Effective Field Theory [7]. An important feature of this study was its double-blind nature, meaning the experimental results were obtained without any knowledge of the theoretical results, and vice versa. All four results were collected by Dr. Sherry Yennello of the Texas A&M University Cyclotron Institute and then revealed to the participants on March 8th, 2024. This comparative study aims to showcase the predictive power of modern theory with respect to cluster configurations of nuclei. A paper discussing the comparison of experimental and theoretical results is currently underway.

[1] A.M. Mukhamedzhanov *et al.*, J. Phys. Conf. Ser. **202**, 012017 (2010).

[2] C.R. Brune, W.H. Geist, R.W. Kavanagh, and K.D. Veal, Phys. Rev. Lett. **83**, 4025 (1999).

[3] E. Harris *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2021-2022), p. IV-56.

[4] E. Harris *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2021-2022) p. I-26.

[5] K. Kravvaris and A. Volya, Phys. Rev. Lett. **119**, 062501 (2017).

[6] K.D. Launey, A. Mercenne, and T. Dytrych, Annu. Rev. Nucl. Part. Sci. **71**, 253 (2021).

[7] D. Lee, Prog. Part. Nucl. Phys. **63**, 117 (2009).