Spectroscopic quadrupole moment of the 2^+ state at 4.439 MeV in ^{12}C

M. Kumar Raju[1,2],* J. N. Orce[1], C. V. Mehl[1], N. Erasmus[1], T. E. Drake[3], M. K. Djongolov[3], P. Navratil[3], G. C. Ball[3], H. Al Falou[3], R. Churchman[3], D. S. Cross[3], S. Triambak[1,2], P. Finlay[3], C. Forssen[3], A. B. Garnsworthy[3], P. E. Garrett[3], G. Hackman[3], A. B. Hayes[3], R. Kshetri[3], J. Lassen[3], K. G. Leach[3], R. Li[3], J. Meissner[3], C. J. Pearson[3], E. T. Rand[3], F. Sarazin[3], S. K. L. Sjue[3], C. S. Sumithrarachchi[3], C. E. Svensson[3], E. R. Tardiff[3], A. Teigelhoefer[3], S. J. Williams[3], J. Wong[3], and C. Y. Wu[3]

[1] *Department of Physics, University of the Western Cape, Belleville-7535, South Africa*
[2] *Department of Nuclear Physics, iThemba Labs, Somerset West, South Africa and*
[3] *TRIUMF Colloboration, 4004 Wesbrook Mall, Vancouver, British Columbia V6T 2A3, Canada*

Motivation

Information about the nuclear shape and degree of quadrupole collectivity of even-even nuclei can be obtained by determining the diagonal matrix elements $\langle 2_1^+ \parallel \hat{E}2 \parallel 2_1^+ \rangle$. Coulomb excitation measurement at energies well below the Coulomb barrier selectively excite collective states with cross sections that are a direct measure of the electromagnetic matrix elements. The reorientation effect (RE) is a second order effect in Coulomb-excitation theory and provides information on diagonal matrix elements. The latter are related to the spectroscopic quadrupole moment (Q_s) which in turn gives direct information on shape of the nucleus.

The long standing predictions of α-cluster states in ^{12}C plays an important role to account for the observed abundance of carbon in the Universe. The α-cluster configurations based on 0_2^+ state (Hoyle state) at 7.65 MeV has considerable mixing with the 0^+ ground state and decays to it via the 2_1^+ excited state. Theoretically, the predictions of various model calculations such as isomorphic shell model, rotational models, α-particle model etc., are inconsistent with each other and suggest the ground state of ^{12}C associate with deformation ranging from spherical to strong oblate [2, 3]. The quantitative information about quadrupole moments in different scattering experiments such as electron scattering, hadron scattering performed at above Coulomb barrier energies reported β values spanning from $\approx +0.6$ to -1.37 [4] and did not show conclusive evidence for oblate ground state deformation in ^{12}C. Most of these experiments were insensitive to the sign of the quadrupole moment.

The difficulty in measuring the $Q_s(2_1^+)$ in ^{12}C lies in its high excitation energy of 4.439 MeV. The experimental yields in scattering experiments are small and such a measurement demands highly-efficient detection systems and intense beams to do a precise measurement. To date there was only one attempt [5] in measuring the $Q_s(2_1^+)$ in ^{12}C through Coulomb-excitation RE using a ^{208}Pb target. This study reported $Q_s(2_1^+) = +6(3)$ efm^2. This value agrees with models suggesting oblate deformations and excludes the spherical solutions suggested by HF calculations. However, the reported value has a large uncertainty due to the assumption of a polarizability parameter of $\kappa = 1$ inferred from shell model calculations and the poor resolution of particle spectra from which the excitation probabilities were measured. Thus it is of prime importance to determine the accurate value of $Q_s(2_1^+)$ in ^{12}C to miring between mean-field and cluster structures in ^{12}C and provide an stringent test of theoretical predictions.

Experimental Details and Results

We aimed at determining the sign and magnitude of $Q_s(2_1^+)$ in ^{12}C using the RE in a safe Coulomb excitation measurement. The 2_1^+ state was excited through inelastic scattering of ^{12}C beams at 4.97 MeV/u impinging on a 3

*Electronic address: kumar8284@gmail.com

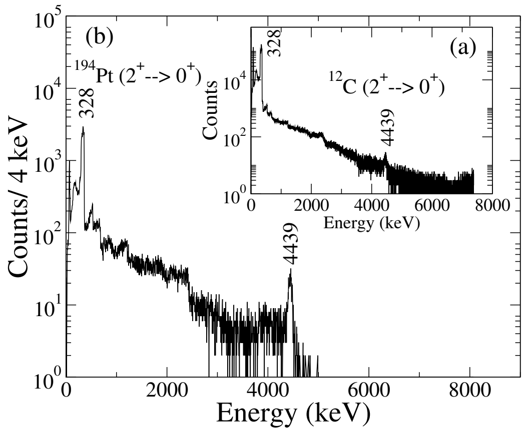

FIG. 1: Shows the sum $\gamma-$ray spectrum corresponding to the one hit in a Tigress $\gamma-$ray detector and two hits in the S2 double-sided silicon detector with (a) Doppler correction and (b) Doppler correction + energy sharing and inelastic conditions.

mg/cm^2 ^{194}Pt target. The de-excited γ-rays were detected with the highly-efficient and segmented TIGRESS HPGe detector array at TRIUMF, which consisted of 8 TIGRESS detectors. Each of these detector output total of 32 signals from inner core contacts and 32 signals from outer contacts provides information about γ-ray interactions within the detector, helpful for precise Doppler corrections. The scattered charged particles were detected in coincidence with γ-rays using an S2 double sided silicon annular detector. This S2 detector contains 48 rings (24 electronic signals) and 32 sectors. In this experiment, the particle detector covered scattering angles from 30.7° to 61° for the chosen target to detector distance of 19.4 mm.

The data have been collected using high speed (100 MHz) digital data acquisition and sorted offline using the sortshell program and further analysed using the MIDAS and RADWARE packages. The particle spectra were calibrated using the triple-α source (^{239}Pm, ^{240}Am and ^{241}Am) at low energies and Geant4 simulations of elastic peaks at higher energies. The inset of Fig. 1 shows the Doppler corrected sum γ-ray spectrum resulted from the 8 clover detectors in coincidence with particles detected in the S2 detector. A transition of 328 keV from first 2^+ state of ^{194}Pt is visible in the spectrum. This spectrum shows evidence for the 4439 keV γ-ray transition from the 2_1^+ state in ^{12}C. Inelastic particle tagging and energy sharing conditions have been used to clean the γ-ray spectrum.

The effect of energy sharing condition also enables a better selection of the inelastic particle gates. Further, the γ-ray spectrum, shown in Fig. 1, is generated employing inelastic gates in the particle spectra including the energy sharing and prompt timing ($\approx$ 100 ns) conditions which shows the 4439-keV of 2_1^+ state in ^{12}C with a reasonable yield of $\approx$ 1000 counts. Angular distributions of the γ-ray yields are estimated from the GOSIA coupled channel Coulomb excitation calculations and can be compared with experimental yields for the extraction of matrix elements. The polarizabiltiy parameter (κ) is estimated using NCSM calculations which will serve as an input to GOSIA calculations. The Coulomb-excitation curve (Fig. 4 in Ref. 6) overlapped with the well known B(E2:$2^+ \rightarrow 0^+$) in ^{12}C provided the shape of life and details will be presented during this symposium.

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