Experimental investigation of a linear-chain structure in ^{14}C †

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In 1956, Morinaga[1)] came up with the novel idea of a particular cluster state: the linear-chain cluster state (LCCS). Now the LCCS is commonly considered as extreme and exotic, due to its presumed propensity to exhibit bending configurations. A theoretical prediction of LCCS in ^{14}C was made by Suhara and En'yo[2,3)] with an antisymmetrized molecular dynamics (AMD) calculation, yielding a prolate band ($J^\pi = 0^+, 2^+, 4^+$) that has a configuration of an LCCS at a few MeV or more above the ^{10}Be+α threshold. In the present work we applied the ^{10}Be+α resonant scattering method[4–7)] in inverse kinematics to identify the predicted LCCS band in ^{14}C.

The present measurement was performed at the low-energy radioactive isotope beam separator CRIB. The ^{10}Be beam had a typical intensity of 2×10^4 particles per second, and the beam purity was better than 95%. The ^{10}Be beam at 25.8 MeV impinged on the gas target, which was a chamber filled with helium gas at 700 Torr (930 mbar) and covered with a 20-μm-thick Mylar film as the beam entrance window. The measured ^{10}Be beam energy at the entrance of the helium gas target, after the Mylar film, was 24.9±0.3 MeV. α particles recoiling to the forward angles were detected by ΔE-E detector telescopes.

Finally we obtained the excitation function of the ^{10}Be+α resonant elastic scattering for 13.8–19.1 MeV, where events with $\theta_{\rm lab} = 0$–$8°$ ($\theta_{\rm cm}$= 164–180°) were selected. We performed an R-matrix calculation to deduce the resonance parameters. The best fit parameters obtained from the analysis are summarized in Table 1. Although the analysis was performed without any assumption from the theoretical calculation, we identified three resonances perfectly corresponded to the predicted LCCS band; J^π are identical, and their energies and spacings are consistent with the theoretical prediction. We claim this as the strongest indication of the LCCS ever found. It can be also shown that both sets of level energies can be plotted almost on a line, $E_J = E_0 + \hbar^2/2\Im(J(J+1))$, where $\Im$ is the moment of inertia of the nucleus. The linearity allows us to interpret the levels as a rotational band, and the low $\hbar^2/2\Im = 0.19$ MeV implies the nucleus could be strongly deformed, consistent with the interpretation of an LCCS. The experimental Γ_α of these resonances are also compared with the theoretical predictions in terms of the dimensionless partial width θ_α^2 in Table 1, although the precision of both is quite limited. The calculation qualitatively reproduces the feature that the experimental θ_α^2 is anti-correlated with J.

Table 1. The resonance parameters in ^{14}C determined by the present work, compared with the AMD calculation[2)]. Parameters in bold letters are for LCCS predicted in the calculation, and corresponding experimental resonances.

Present Work			
$E_{\rm ex}$ (MeV)	J^π	Γ_α (keV)	θ_α^2
14.21	(2^+)	17(5)	3.5%
14.50	1^-	45(14)	4.5%
15.07	$\mathbf{0^+}$	**760(250)**	**34(12)%**
16.22	$\mathbf{2^+}$	**190(55)**	**9.1(27)%**
16.37	(4^+)	15(4)	3.0%
16.93	(2^+)	270(85)	10.3%
17.25	(1^-)	190(45)	5.5%
18.02	(3^-)	31(19)	1.3%
18.63	5^-	72(48)	9.4%
18.87	$\mathbf{4^+}$	**45(18)**	**2.4(9)%**

Suhara & En'yo[2)]			
$E_{\rm ex}$ (MeV)	J^π		θ_α^2
15.1	$\mathbf{0^+}$		**16%**
16.0	$\mathbf{2^+}$		**15%**
19.2	$\mathbf{4^+}$		**9%**

As investigated in the theoretical calculation of the ^{14}C system, the orthogonality between different quantum mechanical states is considered to play a key role in stabilizing the LCCS. Further studies may reveal whether this mechanism is universal in nuclear systems or particular to ^{14}C.

References

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