Missing-mass spectroscopy of short-lived nuclei at low-momentum transfer region opened by the MAIKo active target

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Summary

The missing mass spectroscopy is a promising method to investigate the structures in unstable nuclei versatile in excitation energy. However, the measurement at forward scattering angles in the c.m. system is technically difficult because the energies of the recoil particles are extremely small. In order to realize the detection of such low-energy recoil particle, we developed a new active target system named MAIKo [1]. MAIKo is based on a TPC in which the detector gas is used as a target gas. Since the scatterings occur inside the sensitive volume of the TPC, the detection threshold for the recoil particles are lowered. The size of the MAIKo TPC is $100 \times 100 \times 140$ mm^3. We introduced the μ-PIC [2] for the amplification and detection of the drift electrons and achieved the finest readout pitch among the existing active target systems.

As the first physics experiment using MAIKo, we performed the alpha elastic and inelastic scatterings off ^{10}C at 68 MeV/u at Research Center for Nuclear Physics, Osaka University [3]. The aim of the experiment is to deduce neutron transition matrix element M_n from the ground state to the 2_1^+ state at $E_x = 3.35$ MeV in ^{10}C and discuss the $Z = 6$ magicity in the proton-rich carbon isotope.

An almost pure ^{10}C secondary beam with an intensity of 70 kcps was produced from a ^{12}C primary beam at 96 MeV/u. The missing mass spectroscopy with MAIKo was performed to reconstruct the excitation energy in ^{10}C. MAIKo was operated with the He(96%)+CO_2(4%) gas mixture at 500 and 1000 hPa. We successfully detected low-energy recoil alpha particles down to $E_\alpha = 0.5$ MeV with MAIKo as designed, which corresponds to the momentum transfer down to $q = 0.4$ fm^{-1}.

The trajectories of the recoil alpha particles were reconstructed with the Hough transformation. Only the α+^{10}C events were selected from other background events by the track reconstruction algorithm and the particle identification. The parameters in the track reconstruction procedures were optimized from the eye-scanned data samples. The excitation-energy resolution was about 1 MeV in sigma, which was good enough to distinguish the first excited 2_1^+ state at $E_x = 3.35$ MeV from the ground state in ^{10}C. A Monte Carlo simulation was performed to estimate the detection and track reconstruction efficiencies. The differential cross sections of the α+^{10}C elastic scattering and the inelastic scattering exciting the 2_1^+ state were measured at $4.5^\circ < \theta_{\mathrm{c.m.}} < 15^\circ$.

The differential cross section of the α+^{12}C elastic scattering was also measured using a primary ^{12}C beam at 94 MeV/u. The measured cross section was compared with the measurement

under the normal kinematic condition using a ^{4}He beam at 96 MeV/u [4]. We confirmed that both results are consistent quantitatively, demonstrating the reliability of the present measurement with MAIKo.

From the analysis of the cross section of the α+^{10}C elastic scattering, the phenomenological α-N effective interaction and the point-nucleon distribution of the ground state in ^{10}C were determined. The rms radius of 2.6 ± 0.3 fm in ^{10}C is consistent with the theoretical prediction by the AMD calculation [5] and the experimental result of the previous proton elastic scattering [6], but slightly larger than that deduced from the interaction cross section [7].

By comparing the measured cross section of the α+^{10}C inelastic scattering exciting the 2_1^+ state with the DWBA calculation, the neutron transition matrix element of $M_n = 6.9 \pm 0.7\,(\mathrm{fit}) \pm 1.2\,(\mathrm{sys})$ was obtained. The present experiment is the first attempt to determine the neutron transition matrix element in unstable nuclei from the alpha inelastic scattering. The alpha inelastic scattering enables us to deduce the neutron transition matrix element without model ambiguity better than the inelastic proton scattering which has been widely applied to the RI beam experiments.

Because the obtained M_n value in ^{10}C is close to the M_p value in the mirror nucleus ^{10}Be, we concluded that the isospin symmetry in the $A = 10$ system is almost conserved. The ratio of the neutron transition matrix element to the proton transition matrix element was determined as $M_n/M_p = 1.05 \pm 0.11\,(\mathrm{fit}) \pm 0.17\,(\mathrm{sys})$. The ratio close to unity suggests that the recently proposed $Z = 6$ shell closure is less evident in proton-rich ^{10}C nucleus than the neutron-rich side. The fact that M_n/M_p larger than $N/Z = 2/3$ can be attributed to the decoupling of the proton and neutron distributions predicted by the AMD calculation [8].

After the long-standing development since 2011, the first physics experiment using MAIKo has been successfully completed. The MAIKo active target provides a breakthrough to realize the measurement of the alpha inelastic scattering at low momentum transfer region under the inverse kinematic condition. MAIKo is now under an upgrade program to explore more exotic side and it shall be utilized in many incoming RI beam experiments in the near future.

References

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