Strongly suppressed E0 decay from the superdeformed 0^+ state in ^{40}Ca

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Atomic nuclei are composed of two types of fermions, protons and neutrons, and have a wide variety of shapes. In particular, it has been known that extremely deformed states with a 2:1 ratio of major to minor axes, called superdeformed states, exist in nuclei of various masses [1]. Such a state has been observed in a rapidly rotating nucleus (a high-spin state), but it was not well understood how it collapsed from there into a spherical ground state. To understand this mechanism, it was necessary to investigate the transition between the spin 0 states of lowest energy with the same deformation, which best characterizes each deformation, but such transitions from spin 0 states of superdefromed states were not observed except for a few cases.

The ^{40}Ca nucleus is spherical with a magic number of 20 for both protons and neutrons and a ground state of spin 0. In addition, there are 2 spin 0 states in the excited state at 3.3 and 5.2 MeV, respectively, and each of which is a normal-deformed and superdeformed state in the shape of a rugby ball. [2, 3, 4, 5, 6] Thus, the ^{40}Ca nucleus was found to exhibit a characteristic property of coexistence of 3 widely different shapes, and was considered to be a suitable nucleus for the study of the shape coexistence phenomenon, which is unique to the atomic nucleus.

We have succeeded in observing decay transitions from a superdeformed spin 0 excited state to a spin 0 ground state in the ^{40}Ca nucleus for the first time. The γ transition between spin 0 states is prohibited by the angular momentum conservation law, while transitions by electron conversion or electron-positron pair emission are allowed. In order to observe this transition and investigate the mechanism of decay from the superdeformed state, we conducted an international joint experiment using the electron spectrometer (Super-e) with a superconducting solenoid magnet at the accelerator facility of the Australian National University (see Fig. 1) [7, 8, 9]. The excited 0^+ states were populated via the ^{40}Ca(p,p') reaction with 8.6 MeV proton beam, and transitions from the superdeformed state to the ground state, from the superdeformed state to the normally deformed state, and from the normally deformed state to the ground state were successfully observed. [10]

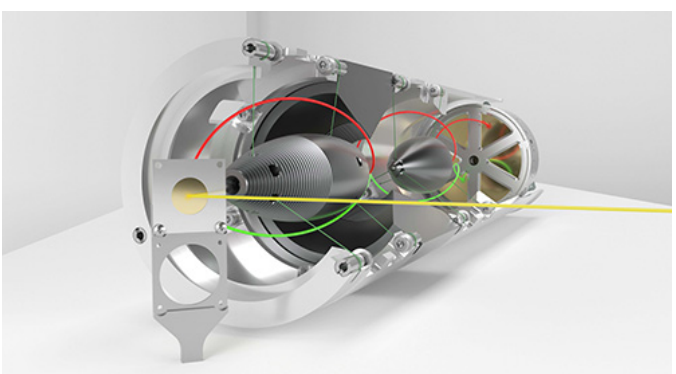

Figure 1: Inner bore of the Super-e spectrometer. The yellow lines in the figure show the beam being irradiated to the target, and the electrons and positrons emitted from it (red and green lines) are guided to the Si detector placed downstream of it. The setup shown is surrounded by a superconducting solenoidal magnet.

Since transitions between the states with completely different shapes are forbidden, the discovery of these transitions implies that the three spin 0 states are mixed, with spherical, normally deformed, and superdeformed as main components, respectively, while each state also have other shape components. In other words, the deformation in the mixed state is considered to collapse from the superdeformed state to the spherical state via a transition between similar components. This reflects the fact that nucleus is a quantum system having both particle and wave properties, and that different deformed states are mixed due to the tunneling effect. In particular, we observed that the transtion from superdeformed state to the spherical ground state is significantly suppressed compared to the other transitions as shown in Fig.2.[11] A large-scale shell model calculations revealed that the transitions from the superdeformation to the spherical ground state is suppressed because of interference between the different shape components, which cancel out the strength each other as schematically illustrated in Fig.3.

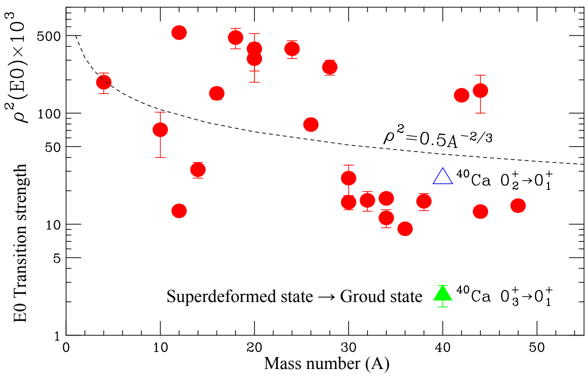

Figure 2: E0 transition intensities with mass less than 50. The green dot shows the transtion strength from the superdeformed state to the ground state, showing the smallest value. The red dots are experimental values of other nuclei, and the dashed line is a curve inversely propotional to the $A^{2/3}$, showing the trend of E0 intensities with respect to the mass number.

Shape coexistence is a special quantum phenomenon that appears in atomic nuclei and has been explored with interest in its discovery itself. So far this phenomenon has been understood using two states mixing model, a spherical state and a deformed state, but in the ^{40}Ca nucleus, three deformations coexist and there is an interference effect between the states, which was found in this study and will give an important insight to further understand the shape coexistence phenomena.

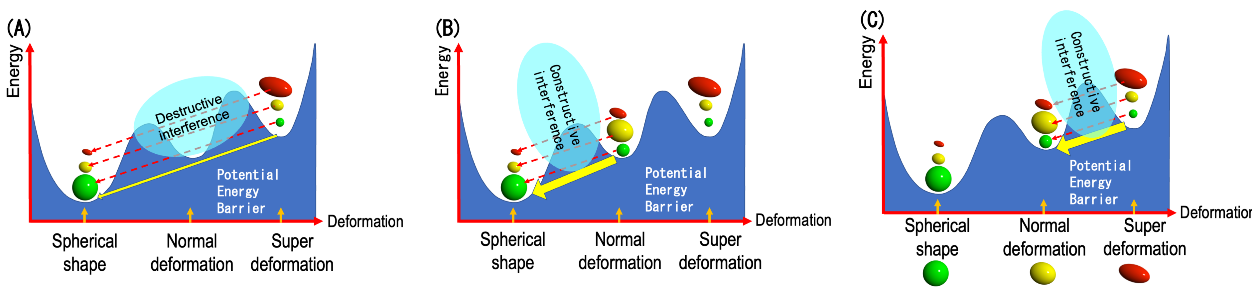

Figure 3: Schematic diagram of three deformed states and electron-positron (e+e-) transitions coexisting in a ^{40}Ca nucleus. (A) superdeformation to spherical, (B) normal deformation to spherical, (C) superdeformation to normal deformation transition.

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