Shape coexistence and mixing in $N \sim 20$ region

Yutaka Utsuno$^1$, Takaharu Otsuka$^{2,3}$, Takahiro Mizusaki$^4$ and Michio Honma$^5$

$^1$ Japan Atomic Energy Research Institute, Tokai, Ibaraki 319-1195, Japan
$^2$ Department of Physics and Center for Nuclear Study, University of Tokyo, Hongo, Tokyo 113-0033, Japan
$^3$ RIKEN, Hirosawa, Wako-shi, Saitama 351-0198, Japan
$^4$ Institute of Natural Sciences, Senshu University, Higashimita, Tama, Kawasaki, Kanagawa 214-8580, Japan
$^5$ Center for Mathematical Sciences, University of Aizu, Tsuruga, Ikki-machi Aizu-Wakamatsu, Fukushima 965-8580, Japan

E-mail: utsuno@nsbox.tokai.jaeri.go.jp

Abstract.
Spherical-deformed shape coexistence in the $N \sim 20$ region is studied with the Monte Carlo shell model calculation. We focused upon the role of the configuration mixing in its description, and found that the deformed state is not correctly positioned until the mixing is treated in a proper way. It is also mentioned that the intruder component in $^{33}$Al is accessible through the measurement of the magnetic moment.

1. Introduction
Since the importance of the configuration mixing in the magnetic moment was for the first time pointed out by Arima and Horie [1] in 1954, the nuclear shell model has been developing to include it as much as possible. Owing to recent progress in solving large-scale shell-model problem such as, for instance, the Monte Carlo shell-model [2] (MCSM) calculation, the shell model now can handle strongly deformed states which need many valence orbits. The $N \sim 20$ region is one of the most interesting and challenging areas for the shell model: a systematic description of the disappearance of the magic structure requires large-scale calculation and a suitable interaction. This disappearance was often discussed in terms of the so-called “island of inversion” picture [3], where the ground-state energies within the pure normal and intruder configurations are compared with each other. Recently, we have performed fully mixed shell-model calculations by MCSM [4], showing that the mixing between the normal and intruder states plays a crucial role in certain nuclei. In the present study, we investigate the shape coexistence in the $N \sim 20$ region based on the MCSM results, aiming to clarify the importance of the configuration mixing in its description.

2. Systematics of spherical-deformed shape coexistence in $N = 20$ isotones
We calculate the energy levels of $N = 20$ isotones from $Z = 15$ to 18, where it is considered that the ground state is spherical and deformed states appear as low-lying states dominating two-neutron excitation across the $N = 20$ shell gap. We then confirm that the MCSM calculation with the SDPF-M interaction [4, 5] nicely reproduces the position of the intruder states.
In order to understand the importance of the correlation, Fig. 1 compares the locations of the deformed \(0^+_2\) state in \(^{36}\text{S}\) and \(^{38}\text{Ar}\) between different approximations of the shell model. In the constrained Hartree-Fock (CHF) method, the deformed states lie higher than those of the full calculation by the MCSM, and its difference rather depends on nucleus. After including the angular momentum projection, the locations become closer to the MCSM. Note that this may be a fortune because the mean-field based calculation results in almost pure \(0\hbar\omega\) and \(2\hbar\omega\) states, whereas the MCSM does not. In the truncation scheme of the shell model, we see large deviations from the MCSM results. Due to the absence of the mixing, the pure \(0\hbar\omega\) vs. \(2\hbar\omega\) calculation taken in the “island of inversion” [3] results in the \(0^+_2\) too closely located to the \(0^+_1\). When we do not include the \(4\hbar\omega\) etc., the excitation energies are too high, because the higher intruder components predominantly pull down the intruder states. Once we reproduce the location of the intruder state with proper treatment of the mixing, the present \(N = 20\) shell gap is confirmed to be appropriate around stable nuclei, too, supporting the shell evolution [6].

3. Intruder-configuration mixing in \(^{33}\text{Al}\) and its effect on the magnetic moment
Along the \(N = 20\) isotone chain, it is certain that the ground states of \(^{32}\text{Mg}\) and \(^{34}\text{Si}\) are dominated by the intruder and normal configurations, respectively. It is thus interesting how much the intruder component is contained in the boundary nucleus \(^{33}\text{Al}\) and how it is detected by experiment. We propose that the magnetic moment, whose experimental value has not yet been published though, is one of the good measures: as the intruder component increases, a partial orbital angular momentum is carried by neutrons, reducing its magnetic moment.

Acknowledgments
This work was supported mainly by Grant-in-Aid for Specially Promoted Research (13002001) from the MEXT, by the RIKEN-CNS collaboration project on large-scale nuclear structure calculation. One of the authors (Y.U.) acknowledges the support in part by Grant-in-Aid for Young Scientists (14740176) from the MEXT, and the Helios computer system in JAERI.

References
[1] Arima A and Horie H 1954 Prog. Theor. Phys. 11 509
[2] Otsuka T Honma M Mizusaki T Shimizu N and Utsuno Y 2001 Prog. Part. Nucl. Phys. 47 319
[3] Warburton E K Becker J A and Brown B A 1990 Phys. Rev. C 41 1147
[4] Utsuno Y Otsuka T Mizusaki T and Honma M 1999 Phys. Rev. C 60 054315
[5] Utsuno Y Otsuka T Glasmaacher T Mizusaki T and Honma M 2004 Phys. Rev. C 70 044307
[6] Otsuka T Fujimoto R Utsuno Y Brown B A Honma M and Mizusaki T 2001 Phys. Rev. Lett. 87 082502