Bubble nuclei within the self-consistent Hartree-Fock mean field plus pairing approach†

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A bubble structure is the depletion of nucleon density at its center, which is caused by the absence of the nucleon on the s-orbitals. The peak of the s-wave function at $r = 0$ significantly contributes to the nucleon density. Therefore, the absence of the s-wave creates the bubble structure. The pairing correlation and the low-ling excitations affect this bubble structure. In this report, we study the evolution of the bubble structure within the self-consistent Skyrme-Hartree-Fock mean field (HF) plus pairing correlation. The latter is included in two ways: within the Bardeen-Cooper-Schrieffer theory (BCS) and within the exact pairing solution (EP)[1)] at finite temperature, which are referred to as the FTBCS and FTEP, respectively. The bubble candidates are the neutron-rich ^{22}O ($N = 14$, $Z = 8$) and doubly-magic ^{34}Si ($N = 20$, $Z = 14$) nuclei. The calculations are performed with the Skyrme-type interaction MSk3. The binding energies (BE) and two proton/neutron separation energies ($S_{2p/2n}$) of these candidate nuclei are fitted to the experimental data by adjusting the parameters G_N and G_Z of the neutron and proton pairing interactions, respectively. The finite-temperature HF (FTHF), whose single-particle occupation numbers follow the Fermi-Dirac distribution, is also used to make a comparison with the FTBCS and FTEP. The bubble structure is evaluated by the depletion factor $F = (\rho_{max} - \rho_{cent})/\rho_{max}$, where ρ_{max} and ρ_{cent} are the maximum and central nucleon densities, respectively.

The numerical calculations are performed within the FTHF, FTBCS and FTEP for ^{22}O and ^{34}Si. The pairing effect is known to be dominant in the region around Fermi surface so that a truncated space with the level $1d_{5/2}$ located below Fermi surface and six levels $2s_{1/2}$, $1d_{3/2}$, $1f_{7/2}$, $2p_{3/2}$, $1f_{5/2}$, and $2p_{1/2}$ above it is taken into account for the neutron shell of ^{22}O and proton shell of ^{34}Si. As for the proton shell of ^{22}O and neutron shell of ^{34}Si, they are closed and therefore are not affected by pairing. For ^{34}Si, the experimental value for the occupation number of the $2s_{1/2}$ level has been measured and reported by Mutschler *et al.*[2)] The pairing interaction parameter G is adjusted to reproduce this value, which is used as the initial input. For ^{22}O, because the occupation number of the $2s_{1/2}$ level is not known, the calculations are based on reproducing its BE and S_{2n} values.

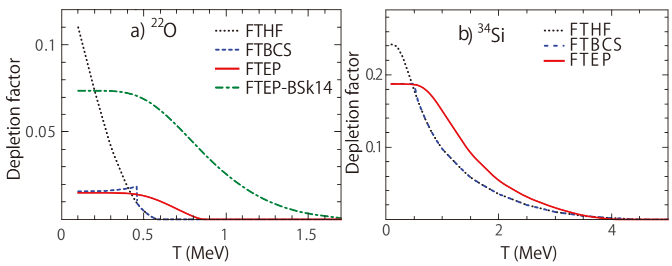

Fig. 1. The depletion factors of ^{22}O and ^{34}Si obtained within the FTHF, FTBCS and FTEP at different temperatures.

The results obtained show that, at $T \simeq 0$, the depletion factors F within the FTBCS and FTEP reach 19% for proton density in ^{34}Si and 2% for neutron density in ^{22}O, whereas the FTHF without pairing produces the value of F at around 24% and 11% for ^{34}Si and ^{22}O, respectively (at $T = 0.1$ MeV). These results indicate that the effect of pairing correlation on the bubble structure is strong in the neutron-rich nucleus ^{22}O, and weak in the doubly-magic nucleus ^{34}Si. With increasing T, the bubbles in these nuclei become less pronounced and completely disappear when T reaches the critical value T_F. The value of T_F in ^{34}Si is around 4 MeV within the FTBCS and FTEP, whereas, for ^{22}O, it is 0.57 MeV within the FTBCS and 0.85 MeV within the FTEP (Fig. 1). This difference can be explained by the fact that the BCS pairing gap Δ collapses when T reaches a critical value $T_c = 0.57\Delta$ $(T = 0)$, which makes the depletion factor coincide with that predicted by the FTHF, whereas the EP pairing gap is always finite with increasing T. This phenomenon causes a significant difference in T_F for the neutron-rich nucleus ^{22}O, where the pairing correlation is dominant. On the other hand, this phenomenon does not seem to take place in the doubly-magic nucleus ^{34}Si. The BSk14 interaction, which is also used in predicting the neutron bubble in ^{22}O, shows a small pairing in this nucleus instead of strong pairing obtained by using the MSk3 interaction. This indicates that the MSk3 is more suitable than the BSk14 in our study.

References

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