Neutron shell structure of ^{23,25}F and oxygen neutron dripline anomaly

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The nuclear shell model proposed by Mayer[1)] is a cornerstone for understanding the nuclear structure. The model assumes that each nucleon moves independently and uncorrelated, and is described by a single-particle state (SPS) in a mean field. Nuclei with a doubly magic core plus a single nucleon should be well described using SPS, so that the spectroscopic factor (SF) of the single nucleon is almost unity; for example, the SFs of the valance protons in ^{17}F, ^{41}Sc, ^{49}Sc, and ^{209}Bi are 0.8 ~ 1.1.[2-6)]

A decade ago, ^{24}O was found to be doubly magic[7)], and the oxygen neutron dripline stops at N = 16. In contrast, the neutron dripline of fluorine was extended to N = 22, into the pf-shell, with only one proton on the sd-shell. Therefore, it is worthy to study the single-particle properties of ^{25}F because of the oxygen neutron dripline anomaly[8)].

The one proton quasi-free knockout reactions on ^{23,25}F were studied in the SHARAQ04 experiment at RIBF, RIKEN. [9)] The experimental result was reported in Ref. 10 and is showed in Fig. 1. We found that the ground state to ground state SFs of ^{25}F(p,2p) and ^{23}F(p,2p) reactions are ~ 0.4, which is much less than unity. At first glance, this may indicate that the 0d$_{5/2}$ proton is not in an SPS. However, the total single-particle strength (sum of SFs) of the valance proton is close to unity for ^{25}F (and most probably for ^{23}F). This means that the 0d$_{5/2}$ proton is in an SPS, and the single-particle strength of the 0d$_{5/2}$ proton is fragmented.

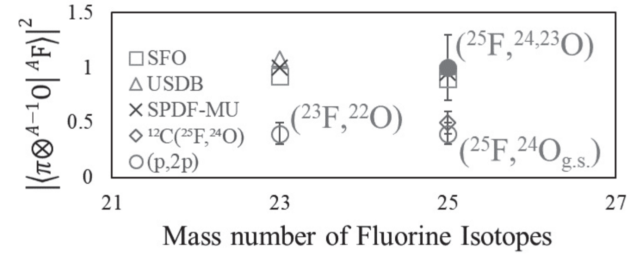

Fig. 1 Experimental and theoretical spectroscopic factors of ^{23}F and ^{25}F. The solid circle is the total strength of the (^{25}F,^{24,23}O) reaction. The result for ^{12}C(^{25}F,^{24}O) is taken from Ref. 15.

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We propose the wavefunction of ^{23,25}F to be

$$|{}^{A}F\rangle = |\pi\rangle\otimes\left(\beta_0|{}^{A-1}O_{g.s.}\rangle + \sum_i \beta_i|{}^{A-1}O^i\rangle\right),$$

where A is the mass number, β_j is the square root of the SF, $|\pi\rangle$ is the wavefunction of the 0d$_{5/2}$ proton, $|{}^{A-1}O_{g.s.}\rangle$ is the wavefunction of the ground-state oxygen core, $|{}^{A-1}O^i\rangle$ is the wavefunction of the oxygen core in the i-th excited state, and the symbol $\otimes$ represents the angular and isospin coupling and anti-symmetry operator. The wavefunction of the 0d$_{5/2}$ proton is factored out and represents an SPS. The ground state of fluorine has many components of the excited oxygen core, and the neutron-shell structure of fluorine is different from that of oxygen.

The mechanism of change of the neutron shell structure could be due to the tensor force between the 0d$_{5/2}$ proton and the sd-shell neutrons.[11)] The proton lowers the 0d$_{3/2}$ neutron orbit and then increases the neutron configuration mixing, which creates many components of the excited oxygen core.

The result was compared with shell model calculation using the psd (SFO[12)]), sd (USD-B[13)]), and sd-pf (SDPF-MU[14)]) model space. All interactions above predict the SF to be close to unity without fragmentation (Fig. 1). This is because the neutron shell is rigid. The experimental result suggests that the tensor force could be larger near the dripline.

In conclusion, the SPS of the valance protons of ^{23,25}F were studied. The result shows that the proton is in an SPS and the neutron-shell structure is modified significantly. The experimental result may provide a new insight into the oxygen dripline anomaly.

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