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Stability island near the neutron-rich ^{40}O isotope

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Abstract. Stability with respect to neutron emission is studied for nuclear isotopes $^{4-12}$He, $^{14-44}$O, $^{38-80}$Ca in the framework of Hartree-Fock approach with Skyrme forces SLy4 and Ska. The data shows possible existence of stability island around ^{40}O.

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Here we present our first in series of results in searching for highly neutron-excessive stable nuclei within the HF framework, that are outdistanced from conventional nucleon stability line. The calculation method is Hartree-Fock approximation with Skyrme effective interaction [1].

$$V_{ij} = t_0(1 + x_0P_\sigma)\delta(\mathbf{r}) + (1/2)t_1(1 + x_1P_\sigma)\left[\mathbf{k}'^2\delta(\mathbf{r}) + \delta(\mathbf{r})\mathbf{k}^2\right] + t_2(1 + x_2P_\sigma)\mathbf{k}'\delta(\mathbf{r})\mathbf{k} + (1/6)t_3(1 + x_3P_\sigma)\rho^\alpha(\mathbf{R})\delta(\mathbf{r}) + iW_0\left[\mathbf{k}' \times \delta(\mathbf{r})\mathbf{k}\right](\sigma_i + \sigma_j)$$

where $\mathbf{r} = \mathbf{r}_i - \mathbf{r}_j$, $\mathbf{R} = (\mathbf{r}_i + \mathbf{r}_j)/2$, $\mathbf{k} = -i(\overrightarrow{\nabla}_i - \overrightarrow{\nabla}_j)/2$, $\mathbf{k}' = i(\overleftarrow{\nabla}_i - \overleftarrow{\nabla}_j)/2$, $P_\sigma = (1+\sigma_i\sigma_j)/2$. Parameters are given in table 1. We have used the set of parameters Ska and compared the results with the most widely used set SLy4. In [2] we have shown that for deformed nuclei ^{25}Mg and $^{29-31}$Si the most satisfactory description of observed spectra comes with the set Ska. Pairing effects were included in the standard way with the pairing constant $G = 19/A$ both for protons and neutrons and were restricted to the space of bounded one-particle states. Taking into account the continuous spectrum increases the pairing effects near the drip line [3] and thus may only increase the nucleon separation energy as well as stability with respect to nucleon emission.

We have looked for stability islands around isotopes $^{4-12}$He, $^{14-44}$O and $^{38-80}$Ca and analyzed how results depend on forces we have used. For isotopes $^{4-12}$He our results on one- and two-neutron separation energies matched already known ones from [4]. For Helium the last stable isotope with respect to two-neutron emission is ^{8}He.

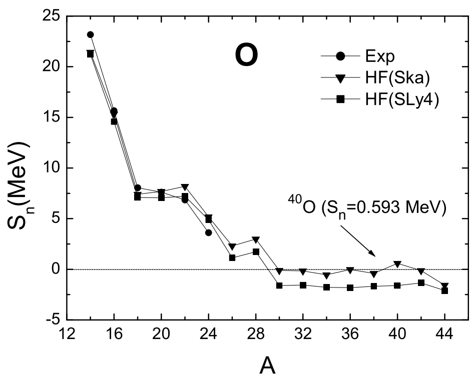

Fig. 1. Calculated separation energies of one-neutron S_n for isotopes $^{14-44}$O with different choices of Skyrme forces compared to the experimental data.

Comparison with experiment (see the figures) shows that both Ska and SLy4 equally well describe the known experimental data. The large separation energy of one and two neutrons in the stable isotope ^{24}O indicates the possible existence of heavier stable isotopes, yet presently it is in contradiction with the experimental data. Our calculations predict the existence of stable ^{26,28}O which are also predicted as stable in [4,5]. In our calculations with forces Ska we have found that the oxygen isotope ^{40}O is stable. Its stability is seen in fig. 1, where we did not plot the two-neutron separation energy for ^{40}O because all its neighboring isotopes are unstable. With forces SLy4 this isotope appears to be unstable with respect to one-neutron

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Table 1. Parameters of the Skyrme forces.

Force	t_0 (MeV fm^3)	t_1 (MeV fm^5)	t_2 (MeV fm^5)	t_3 (MeV fm$^{3+3\alpha}$)	x_0	x_1	x_2	x_3	W_0 (MeV fm^5)	α
SLy4	−2488.91	486.82	−546.39	13777.0	0.834	−0.344	−1.0	1.354	123.0	1/6
Ska	−1602.78	570.88	−67.70	8000.0	−0.020	0.0	0.0	−0.286	125.0	1/3

Table 2. Calculated values of binding energy E, neutron and proton separation energy $S_{p,n}$, root-mean-square radii $r_{p,n}$ quadrupole moments $Q_{p,n}$ and deformation parameters $\beta_2^{p,n}$ for the stable isotope ^{40}O as calculated with Ska forces.

E (MeV)	S_n (MeV)	S_p (MeV)	r_n (fm)	r_p (fm)	Q_n (e^2 fm^2)	Q_p (e^2 fm^2)	β_2^n	β_2^p
168.274	0.593	36.822	4.202	2.943	0.031	0.003	0.004	0.004

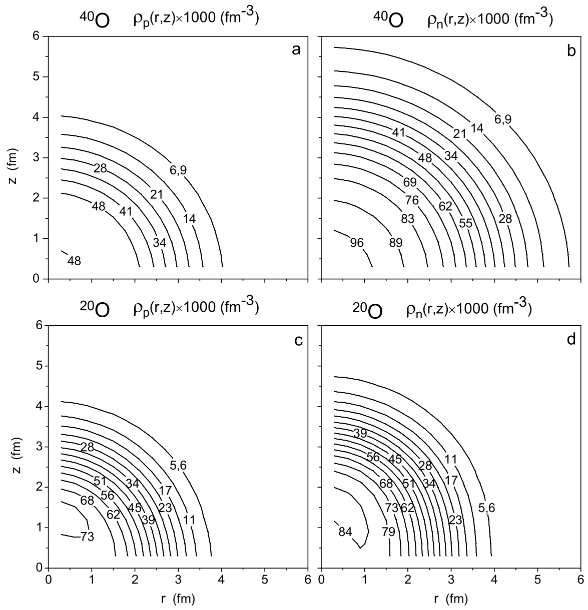

Fig. 2. The map of proton ρ_p and neutron ρ_n distributions calculated for ^{40}O (panels a, b) and for ^{20}O (panels c, d).

emission, though the last filled level is close to zero and one can talk about "quasistability" in this case. From nucleus to nucleus the situation repeats itself, whenever the nucleus is "quasistable" with interactions Ska, then it is "quasistable" with interactions SLy4. In all investigated cases the last filled level for nuclei close to nucleon stability borderline always had a negative parity. And under "quasistable" we mean that this nucleon has a non-zero orbital momentum and the resulting centrifugal barrier prevents the neutron from emission at its low energies.

The obtained data for ^{40}O is given in table 2. One can see from table 2 that the values of proton and neutron deformation for ^{40}O are negligibly small. The map of proton and neutron distributions in r, z coordinates (incorporating the symmetry of the problem) for ^{40}O is shown in fig. 2. Figure 2 also compares the given distributions with the same maps for ^{20}O. One can see from these figures that although the proton "cloud" is expanding it remains coated with the neutron halo which is about 2 fm thick. We claim that the stability of ^{40}O with Ska forces compared to its instability with SLy4 forces stems from the difference in $t2$ and $x2$ components of the Skyrme force.

Preliminary calculations of nearby isotopes showed that there are stable isotopes around ^{40}O among even-even nuclei, namely ^{40,42,44}Ne with one-neutron separation energies are respectively $S_n = 0.13, 0.43, 0.1$ MeV and ^{44,46}Mg with one-neutron separation energies $S_n = 0.8, 0.67$ MeV. These stable isotopes were also found with Ska forces and except ^{44}Mg they lie beyond the conventional stability valley.

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