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TITLE: NUCLEAR GROUND-STATE SHAPES FOR NUCLEI WITH 16<A<280

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NUCLEAR GROUND-STATE SHAPES FOR NUCLEI WITH 16 < A < 280

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We have recently developed a new macroscopic-microscopic model, based on a Yukawa-plus-exponential macroscopic model and a folded-Yukawa microscopic model, with new terms included to account for previously neglected physical effects (1). With this model we have calculated the nuclear ground-state mass and shape for 4023 nuclei by minimizing the total energy, \( E(Z, N, \text{shape}) \) with respect to \( \xi_z \) and \( \xi_y \) shape coordinates. Full details of the calculation are given in ref. (1); the calculated ground-state mass excess, electric quadrupole moment \( Q_Q \) and hexadecapole moment \( Q_M \) are tabulated in ref. (2). Here we shall focus our discussion on some results that are obtained for the ground-state shapes.

The ground-state shapes tabulated in ref. (2) are instructively displayed in terms of a color plot. In col. fig. 1† we display the absolute value of \( \xi_z \) as a function of neutron number \( N \) and proton number \( Z \). The well-known deformed actinide and rare-earth regions stand out clearly. In the actinide region the absolute value of the deformation coordinate \( \xi_z \) is always less than 0.25, in the rare-earth region always less than 0.3 (more precisely always less than 0.28).

However it is clear from col. fig. 1 and ref. (2) that for lighter nuclei other, even more deformed regions exist, usually far from the line of beta-stability. The most deformed regions are

1) \( Z \sim 38, \quad N \lesssim 44; \)
2) \( Z \sim 38, \quad N \gtrsim 58; \)
3) \( Z \sim 11, \quad 9 \lesssim N \lesssim 15 \) and
4) \( Z \sim 11, \quad 20 \lesssim N. \)

† This and subsequent color figures are not published here for typographical reasons.

‡ Alexander von Humboldt Senior US Scientist Award.

\( \xi_z \) is the deformation coordinate in the microscopic model.
For experimental results and previous theoretical work on these regions, we refer to refs. (3-6) and to references quoted therein.

It is seen from col.fig. 1 that the present calculation agrees well with the experimentally observed deformations in these regions and also reproduces very well the neutron number where the change from spherical to deformed shape occurs.

Sudden transitions from spherical to deformed shapes often occur because several minima of almost equal height exist in the potential-energy surface. When the neutron number changes, first one minimum, the another will be the deepest one. We illustrate this by plotting the potential energy versus $\xi_2$ for $N\pi$ isotopes in fig. 1 and for $\pi$ isotopes in fig. 2. The energy is plotted relative to the spherical macroscopic Yukawa-plus-exponential energy. The energy in figs. 1 and 2 (and in fig. 3 below) has been calculated with the parameter set 1 of ref. (1). However, since the energy is plotted relative to another energy, the results would only have changed by a few tenths of a MeV, at most, had the final parameter set 8 been used. The energy plotted in figs. 1 and 2 has been minimized with respect to $\xi_2$.

The root-mean-square error in the ground-state masses, calculated with the final parameter set 8, of 1323 nuclei for which experimental masses are known with errors less than 1 MeV is 0.835 MeV (cf. ref. (1)). We display in col.fig. 2 the discrepancy (calculated mass - experimental mass) as a function of $N$ and $Z$. The discrepancy nowhere shows a tendency to increase far from the line of beta stability. It is interesting to note, however, that quite systematically the discrepancy is most negative, that is the calculated mass is too high, slightly beyond doubly magic numbers. The discrepancy is also rather negative in the actinide region. It was shown in ref. (1), that the discrepancy almost totally disappeared, if deformations were taken into account in the actinide region and mass-asymmetric $\xi_3$ distortions in the region just beyond lead.

In fig. 3 we show the effect of a variation of the mass-asymmetry coordinate $\xi_3$ on the ground-state energy for a few nuclei. The parameters $\xi_2$ and $\xi_4$ are kept fixed at the values obtained for the ground state. The energy is plotted relative to the energy for $\xi_3=0$. Sometimes sizable values of the mass-asymmetry parameter $\xi_3$ are obtained.
Finally we display in col. fig. 3 values of the hexadecapole parameter $\hat{g}_4$ at the ground-state, for nuclei throughout the periodic system.

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Fig. 1
Fig. 3

Energy (MeV)

$E_3$

$\text{P}_3$ distortions at ground-state