Proton-rich exotic heavy nuclei: Self-consistent calculations

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Self-consistent calculations of the potential-energy surface for triaxial quadrupole deformations have been performed for 15 proton-rich cadmium and samarium isotopes. The light Cd isotopes show the expected transition towards spherical nuclei near the doubly magic ^{100}Sn nucleus. Proton-rich Sm isotopes are strongly deformed whereas a region of γ instability is found around ^{138}Sm and explained by a shell structure at $N=76$.

The search for the doubly magic $^{100}_{50}\mathrm{Sn}_{50}$ and neighboring nuclei is of particular importance to test the (N-Z) dependence of the nucleon-nucleon interaction. Recent laser spectroscopy measurements on the Cd (Refs. 1 and 2) series extend our knowledge of their ground-state (g.s.) properties (e.g., radii). On the other hand, the region of light rare-earth nuclei ($N<82$ and $Z>50$) is actively investigated both by β decays[3,4] and in-beam spectroscopy.[5,6] Several new isotopes were thus discovered and collective (mostly g.s.) bands have been identified. Moreover the recent results of the He-jet fed on-line mass separator at the Grenoble accelerator[3] have suggested a stable triaxial g.s. shape in ^{138}Sm.

In this work we have restricted ourselves to two isotopic series. Their static properties have been determined through triaxial self-consistent calculations within the Hartree-Fock plus Bardeen-Cooper-Schrieffer (BCS) approximation using the Skyrme SIII effective interaction.[7] Pairing correlations have been taken care of through the introduction of a constant pairing matrix element yielding a reproduction of experimental quasiparticle energies when available. For exotic nuclei where such data are missing, we have extrapolated the pairing strength from the closest known nuclei. Besides, it has been checked (see, e.g., Ref. 8) that a moderate variation of this parameter does not affect very much the relative energies and not at all the location of potential energy surface extrema. The variational equations have been solved by discretization inside a box as discussed in Ref. 8.

First, we have studied the cadmium isotopes ($Z=48$). From the magic number $N=50$ up to $N=62$, we have calculated all the even isotopes and below $N=50$ we have only considered $N=48$ and 44, as the potential energy surface varies slowly in this region. The second series is the Samarium one for which we have calculated the even isotopes from $N=70$ to $N=80$ together with two isotones of ^{138}Sm (^{136}Nd and ^{140}Gd). Partial results obtained with the same force have already appeared in Ref. 9 where results of axially symmetrical calculations for four cadmium isotopes have been discussed in Ref. 10 for one of the considered samarium isotopes.

The potential energy surfaces of nine even cadmium isotopes (^{92}Cd and $^{96-100}$Cd) are displayed in Fig. 1. The energy surfaces show a smooth trend from moderately soft prolate nuclei ($^{110-104}$Cd) to spherical nuclei ($^{100-92}$Cd). For the ^{110}Cd nucleus a shallow secondary minimum exists on the oblate axis. When decreasing N, it merges with the prolate minimum into a spherical equilibrium solution for ^{100}Cd.

Samarium isotopes ($N>82$) have been already studied within phenomenological mean field[11–13] and Hartree-Fock-Bogoliubov[14,15] approaches. For $N<82$, the calculated potential energy surfaces are shown in Fig. 2. Due to the proximity of the neutron magic number $N=82$, the ^{142}Sm nucleus is still spherical. A softness in the γ direction appears for the ^{140,138,136}Sm isotopes. Whereas the ^{138}Sm minimum is found for $\gamma=25°$ and lies 0.6 and 0.7 MeV below the two local axial minima (which are almost degenerate in energy), the valley in the γ direction is very shallow for the ^{136}Sm and ^{140}Sm nuclei. Moreover, the spherical barrier heights are 0.8, 2.5, and 4.3 MeV in ^{140,138,136}Sm, respectively.

The possible breaking of axial symmetry occurring during the transition between quasispherical and well-deformed nuclei is supported by a triaxial rotor analysis[16] of the available spectroscopic data in proton-rich samari-

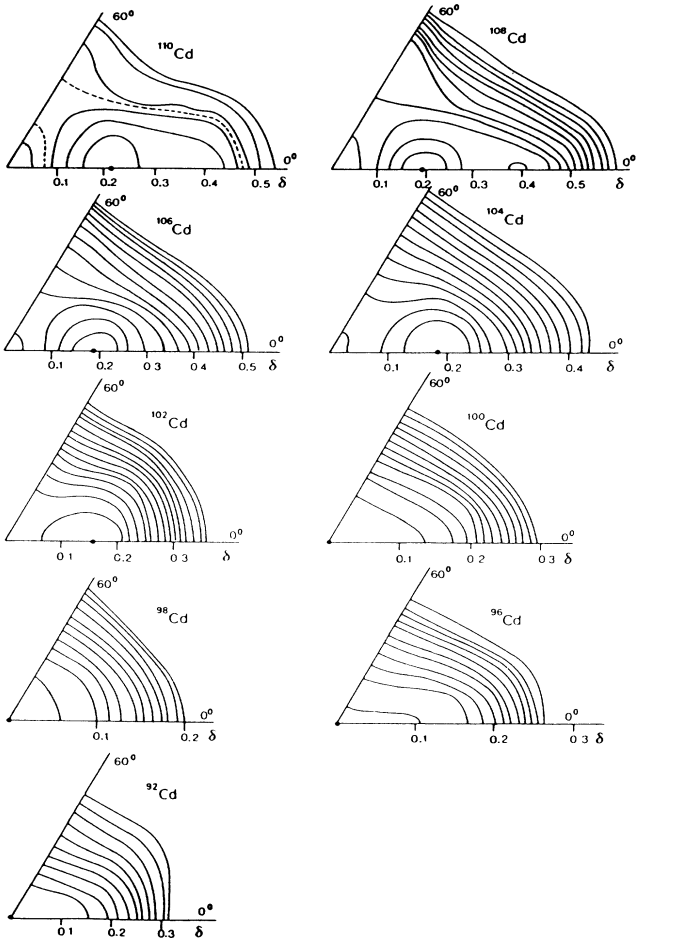

FIG. 1. Potential energy surfaces for various Cd isotopes. The distance between two contour lines corresponds to a variation of 0.5 MeV. The solid circle indicates the location of the absolute minimum and the origin of the plotted (relative) energies. The polar coordinate δ is defined in terms of the quadrupole moment Q_0 (see Ref. 9) expressed in fm^2 by $\delta = Q_0 A^{-5/3}$.

um isotopes obtained[3] at the Systeme-Accélérateur-Rhône-Alpes (SARA) (Grenoble). Indeed, for a triaxial rotor the first 4^+ is found at a higher energy than the second 2^+, as found experimentally for the ^{138}Sm and ^{140}Sm nuclei. Furthermore, the ratio $R = E^{(1)}_{4^+}/E^{(1)}_{2^+}$ should be equal to 2.5 at $\gamma = 30°$. Experimentally one gets 2.57 for ^{138}Sm. The calculated γ instability is related to the low density of neutron single-particle states in the vicinity of the deformation $\beta \sim 0.2$ and $\gamma = 30°$ for $N = 76$.

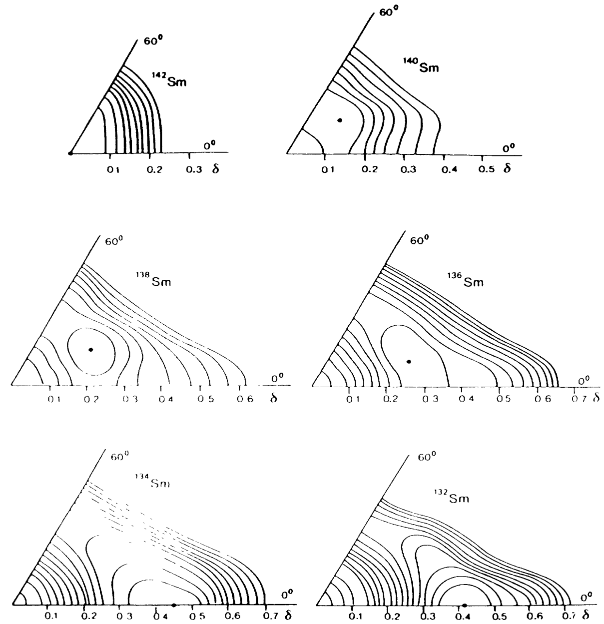

FIG. 2. Same as Fig. 1 for various samarium isotopes.

The neutron origin of the triaxial shell effect is confirmed by the calculated energy surfaces of the neighboring isotones of ^{138}Sm (^{136}Nd, ^{140}Gd) which also fulfills experimentally the two above discussed conditions for triaxiality. (It should, however, be noted that a γ-soft vibrator can also produce the same pattern.)

More and more rigidly deformed solutions are found upon further decreasing N which correspond to rather large mass quadrupole moments $Q_0 = 1565$ fm^2 (1424 fm^2 resp.) for ^{134}Sm (^{132}Sm resp.). Available spectroscopic data[5,17,18] are consistent with our results.

A paper by B. D. Kern *et al.* has appeared[19] which includes potential-energy surfaces for some proton-rich samarium isotopes evaluated through a phenomenological mean-field approach in qualitative agreement with the results of our microscopic calculations.

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