New "Octupole-driving particle numbers" from examination of 3_1^- state energies

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The systematic behavior of 3_1^- states is used to identify N and Z values at which maximum octupole collectivity occurs. The results are used to suggest nuclei in which static octupole deformation might appear.

Substantial experimental evidence that extensive regions of statically octupole deformed nuclei occur in the $A = 218-229$ and $A = 144-155$ regions has now been obtained, and searches for strong octupole effects in other nuclei are under way.[1] From a microscopic point of view, octupole collectivity originates in the interaction between the unique parity orbit in a major shell and the common parity orbit having both orbital and total angular momentum $3\hbar$ less than that of the unique parity orbit.[2] The nuclei in which the strongest octupole effects occur are those in which Fermi surfaces of both neutrons and protons lie between the two interacting orbits. By citing such an argument and assuming a particular arrangement of single-particle levels, Nazarewicz *et al.*[3] have proposed that the nuclei with the strongest octupole correlations, and therefore the best candidates for static octupole deformation, occur when N and Z are equal to what they call the "octupole-driving particle numbers" (ODPN's), 34, 56, 88, and 134. It should be emphasized that the assignment of these numbers depends on the ordering of the single-particle orbits and, less critically, on the spacing between the orbits. However, single-particle energies can change as N and Z change. Consequently, the ODPN's proposed by Nazarewicz *et al.*[3] may not be appropriate everywhere, and a way of testing these numbers by means of a comparison with data is desirable.

A simple observation regarding the energies of 3_1^- states, which are octupole vibrational states in most nuclei, and octupole deformation is the inspiration for such a test: Nuclei which have the greatest degree of octupole collectivity—octupole deformed nuclei—have the lowest 3_1^- state energies, $E(3_1^-)$. In both regions for which static octupole deformation has been proposed (near $A = 224$ and 145), the 3_1^- state energies[4] are extraordinarily low and achieve local minima with respect to both N and Z, as shown in Figs. 1 and 2. In the mass 224 region (Fig. 1), 3_1^- state minima are seen for $N = 134-136$ and $Z = 88-90$, at the core of the region of possible octupole deformation. The $A = 145$ region (Fig. 2) is somewhat more complex; however, a minimum seems to occur at $N = 88-90$. The minimum with respect to Z depends on neutron number, but is near $Z = 56$ when $N = 88-90$, once again at the center of the proposed octupole deformation region. In the present work, the ODPN's of Nazarewicz *et al.*[3] are tested by finding if they correspond to the N and Z values for which 3_1^- state energies achieve local minima in the $A = 80$, 100, and 130 regions.

The $Z = 30-50$, $N = 30-50$ region is one in which the 3_1^- state minima are quite different from those which would be predicted using the ODPN's. The ODPN 34 would imply that the lowest 3_1^- state energy should occur at $N = Z = 34$ (^{68}Se); however, Fig. 3 clearly demonstrates that the 3_1^- energy minima occur at higher N and Z values. The N value best corresponding to minimum $E(3_1^-)$ is 40. The Z plot is not so conclusive, but $Z = 34$ certainly does not correspond to a minimum. Instead, the minimum seems to lie at $Z = 38$, 40, or 42.

Among the $Z = 30-50$, $N = 50-82$ nuclei the ODPN's of Ref. 3 would imply that the strongest octupole collectivity should occur at $Z = 34$ and $N = 56$, but the available data on 3_1^- states (Fig. 4) indicate otherwise. Clearly no $E(3_1^-)$ minimum occurs at $N = 56$. The behavior of Sn isotopes ($Z = 50$) indicates the minimum occurs at $N = 64-66$, although the behavior of the Cd isotopes may indicate that a higher N is more appropriate. The data do not allow a clear determination of a Z value corresponding to the 3_1^- minimum, although the $N = 50$ isotones suggest $Z = 38$.

The relevant ODPN for the $Z = 50-68$, $N = 60-82$ re-

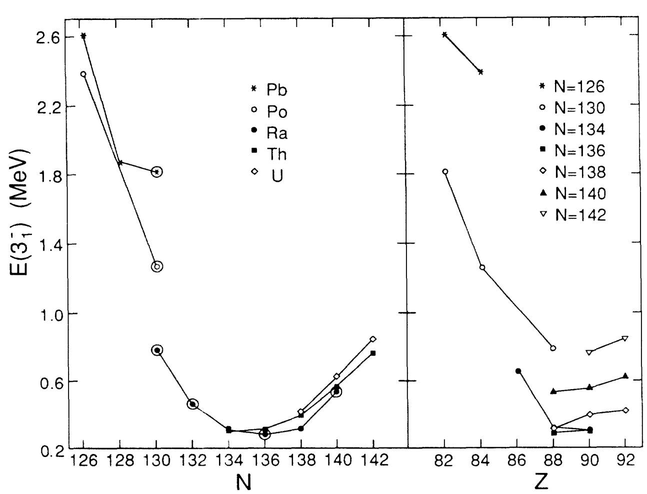

FIG. 1. $E(3_1^-)$ vs N and Z for the $Z = 82-92$, $N = 126-142$ region. Data are taken from the compilation of Ref. 4. Tentative assignments are denoted by circled data points.

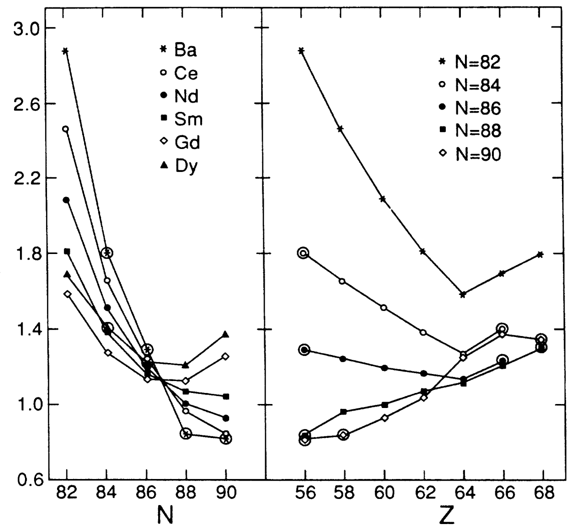

FIG. 2. $E(3_1^-)$ vs N and Z for the $Z=56$–68, $N=82$–90 region. Data are taken from the compilation of Ref. 4. Tentative assignments are denoted by circled data points.

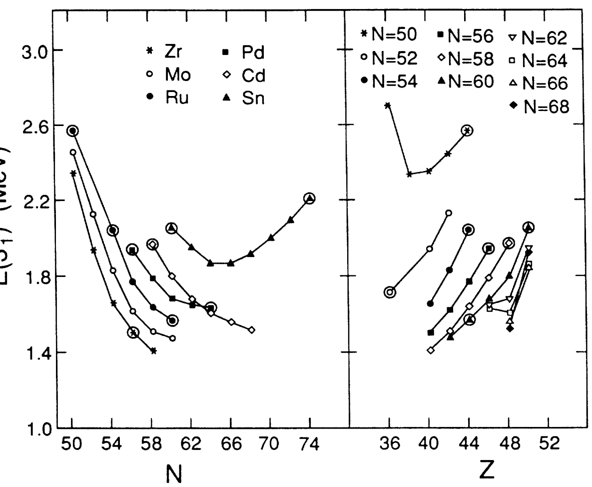

FIG. 4. $E(3_1^-)$ vs N and Z for the $Z=30$–50, $N=50$–82 region. Data are taken from the compilation of Ref. 4. Tentative assignments are denoted by circled data points.

gion is 56, implying that the strongest octupole correlations should occur at $Z=N=56$. Once again, the $E(3_1^-)$ trends provide a different answer. The information on 3_1^- states in this region (Fig. 5) is somewhat scarce; however, the behavior of the Sn isotopes suggests a minimum at $N=64$–66, and the trend seen in the Te and Ba isotopes is consistent with this. Both the $N=80$ and 82 isotone chains indicate a minimum at $Z=64$, and the other isotone chains are consistent with this assignment.

The N and Z values at which the $E(3_1^-)$ minima occur suggest a "new" set of ODPN's. Instead of 34, 56, 88, and 134 as suggested by Nazarewicz *et al.*,[3] the numbers 40, 64, 88, and 134 can be proposed. These numbers are not very different from those suggested previously. They do, however, suggest a slight refinement of current theoretical understanding of octupole behavior and deformation.

In addition, the octupole state minima noted here suggest nuclei where static octupole deformation and other symptoms of strong octupole collectivity may be found. In the $A=80$ region, 3_1^- state minima occur near $N=40$ and $Z=40$, suggesting that the best candidates for octupole deformation in this region would be ^{80}Zr and neighboring nuclei. The trends shown in Fig. 4 would suggest that the highest probability for finding static octupole deformation in the $A=100$ region would be near ^{104}Zr ($Z=40$, $N=64$). No data are available for this nucleus, and little is known about its immediate neighbors; howev-

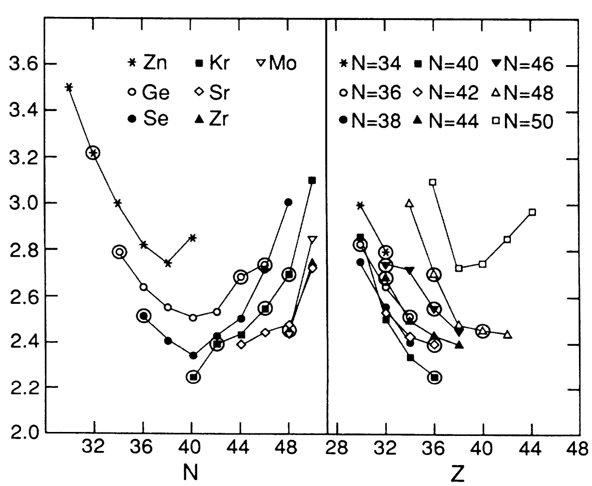

FIG. 3. $E(3_1^-)$ vs N and Z for the $Z=30$–40, $N=30$–50 region. Data are taken from the compilation of Ref. 4. Tentative assignments are denoted by circled data points.

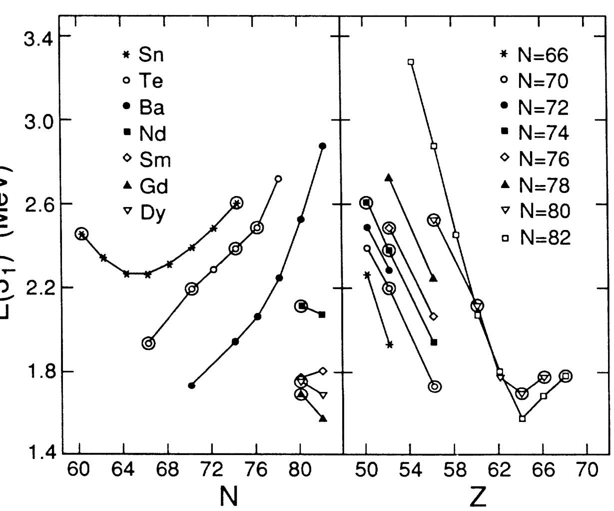

FIG. 5. $E(3_1^-)$ vs N and Z for the $Z=50$–66, $N=60$–82 region. Data are taken from the compilation of Ref. 4. Tentative assignments are denoted by circled data points.

er, recent studies[5] of ^{96}Zr ($N=40$) have revealed that $B(E3;0_{\rm g.s.}\rightarrow 3_1^-)$ is near 70 W.u. (where W.u. represents Weisskopf unit) and is the largest ever observed. Although this nucleus does not possess static octupole deformation in its ground state, the $B(E3)$ value indicates very strong octupole collectivity. It is possible that Zr isotopes nearer to $N=64$ might possess even stronger octupole collectivity and larger $B(E3;0_{\rm g.s.}^+\rightarrow 3_1^-)$ values.

The survey of the $A=130$ region shown in Fig. 5 indicates that the highest probability for finding static octupole deformation in this region would occur near ^{128}Gd ($Z=N=64$). This nucleus is predicted to be beyond the proton drip line;[6] consequently, the most promising experimentally accessible candidates would be the lightest particle-stable Gd isotopes (near the $N=70$ nucleus ^{134}Gd) and the heaviest particle-stable $N=64$ and 66 isotones (near ^{124}Nd and ^{128}Sm). It has recently been shown[7] that experimental results on the high spin states of the nearby $N=70,72$ isotopes of Ba (^{126,128}Ba) are consistent with the presence of static octupole deformation above $J=11$.

In summary, new values for octupole-driving particle numbers (40, 64, 88, and 134) have been proposed on the basis of the systematic behavior of 3_1^- states. This analysis allows the identification of nuclei which may possess static octupole deformation in the $A=80$, 100, and 130 regions.

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