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BRIEF REPORTS

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New nucleus ^{142}Xe: Test of the N_pN_n scheme

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Excited states in the neutron-rich nucleus ^{142}Xe have been determined by observing prompt γ rays in fragments from ^{248}Cm spontaneous fission. Estimates of the lowest excited-state energies in ^{142}Xe based on normal systematics differ considerably from those derived from the N_pN_n scheme. Experimental values are in good agreement with the N_pN_n scheme and illustrate its predictive power in this mass region.

The nucleus ^{142}Xe occupies an interesting position in the mass region $A=130-150$. With $N=88$, $Z=54$ it is very neutron rich and, because of the relatively small numbers of neutrons and protons outside of closed shells, offers a stringent test of procedures for predicting properties of nuclei far from stability. Because of the large neutron excess, up to now there has been no information available on excited states in ^{142}Xe. Here, we report the first results on ^{142}Xe and use the data to show the usefulness of the N_pN_n scheme[1] predictions for this important example.

Figures 1 and 2 show the existing systematics[2,3] of excitation energies of 2_1^+ and 4_1^+ states in the $A=130-150$ mass region. For atomic number $Z\geq56$ the systematics show that the nuclear shapes change from spherical to deformed as the neutron number increases above the closed-shell value $N=82$. Simple extrapolations of smooth curves drawn through the points in Figs. 1(a) and 2(a) suggest that for ^{142}Xe, values for $E(2_1^+)$ and the ratio $E(4_1^+)/E(2_1^+)$ are ~180 keV and ~2.7, respectively. However, such extrapolations are probably unjustified. They anticipate that ^{142}Xe follows the trend of $N=88$ nuclei to become more deformed as Z decreases from the semimagic number $Z=64$, whereas it is clear that, at some point, $E(2_1^+)$ must rise and $E(4_1^+)/E(2_1^+)$ must fall as Z approaches the magic number $Z=50$. Combining the systematics approach and the recognition of the impending shell closure at $Z=50$, one can only guess that ^{142}Xe might have $E(2_1^+)$ somewhere between 150 and 300 keV and the ratio $E(4_1^+)/E(2_1^+)$ somewhere in the range from 2 to 3.

Another scheme for estimating level energies and collective characteristics is the N_pN_n scheme,[1] in which nuclear observables are plotted versus the product of the numbers of valence protons N_p and neutrons N_n rather than against N, Z, or A. This scheme is founded on the well known[4,5] importance of the isospin-zero component of the valence p-n interaction in inducing single nucleon configuration mixing, and hence collectivity and deformation, throughout the nuclear periodic table. The N_pN_n scheme has been successful as a phenomenological tool, and, therefore, its application to ^{142}Xe (with $N_p=4$, $N_n=6$) is an interesting test case. This is all the more so, because it highlights one of the interesting properties[1] of the scheme: Whereas estimates of the properties of unknown nuclei far from stability almost always involve extrapolations when existing data are plotted vs N, Z, or A, estimates using the N_pN_n scheme can often be made by interpolation. Interpolation is possible for ^{142}Xe, with $N_pN_n=24$, and its properties can be predicted using smooth curves drawn through existing data plotted versus the product N_pN_n. Such plots are shown on the right in Figs. 1 and 2, in which are also indicated the predicted values $E(2_1^+)=300(40)$ keV and $E(4_1^+)/E(2_1^+)=2.5(1)$ for ^{142}Xe. The uncertainties quoted are based on the scatter of the data points about the smooth curves

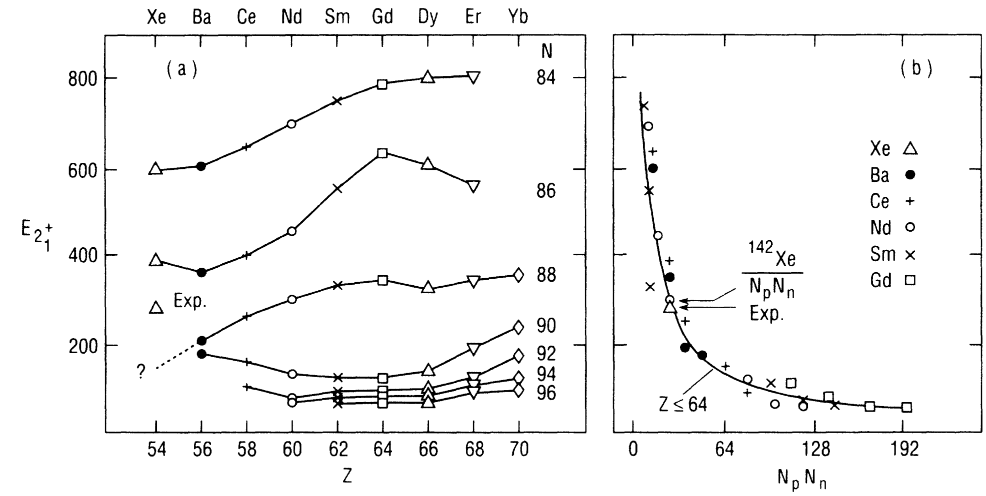

FIG. 1. Normal and N_pN_n plots for $E(2_1^+)$ in the $A=150$ region. Data are from Ref. 2. In each case, expectations for ^{142}Xe are indicated, based on extrapolation on the left and on interpolation along the existing (Ref. 3) curve in the N_pN_n case. The experimental value is also shown on both plots.

drawn through them. The relatively large uncertainty in $E(2_1^+)$ reflects the fact that data on $E(2_1^+)$ for sets of isotopes with different Z fall on curves slightly displaced from each other. This results in a scatter of the $E(2_1^+)$ values around a single smooth curve drawn through them. The Z dependence is less marked when one considers the ratios $E(4_1^+)/E(2_1^+)$, and the N_pN_n prediction for this ratio has less uncertainty.

We have determined for the first time the low-lying level structure of ^{142}Xe by observing prompt γ-γ coincidences in neutron-rich fission fragments resulting from the spontaneous fission of ^{248}Cm. The source was made by mixing 5 mg of ^{248}Cm (6.5×10^4 fissions per second) in the form of CmO_2 with 150 mg of potassium chloride and compressing the mixture to form a thin pellet. The technique for studying nuclei for which one or more γ-transition energies are known has been described elsewhere.[6] Here we describe the procedure used for identifying hitherto unknown transitions in ^{142}Xe and for determining a partial decay scheme for yrast levels in that nucleus. A similar approach has recently been used by Hotchkis *et al.*[7] In spontaneous fission the primary fragments emit a variable number of neutrons, and for ^{248}Cm the total number emitted per fission typically ranges from one to five. A transition in a given nucleus will therefore appear in coincidence with transitions in a number of complementary fragments. Hence, for example, a spectrum of coincident γ rays, obtained by gating on a transition in a particular Mo isotope, will contain transitions in a range of Xe nuclei as well as transitions in the original Mo isotope. Gating on the $2_1^+\rightarrow0_1^+$ transition in ^{102}Mo, a nucleus lighter than the peak yield for Mo isotopes, which is near $A=105$, therefore yields known transitions in ^{140}Xe and candidates for unknown transitions in the higher mass ^{141}Xe and ^{142}Xe. These candidates are established as belonging to Xe nuclei because spectra obtained in coincidence with them show known transitions in a corresponding range of Mo iso-

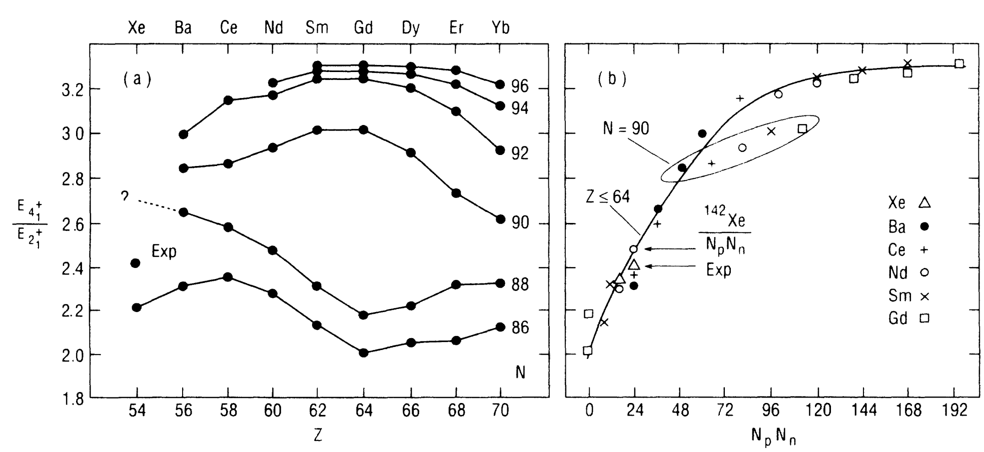

FIG. 2. Similar to Fig. 1 for the energy ratio $E(4_1^+)/E(2_1^+)$. The figure is based on Ref. 3.

topes, as well as other transitions which can be assembled into a consistent level scheme for the candidate Xe isotope. Figure 3(a) shows a spectrum observed in coincidence with the candidate $2_1^+ \rightarrow 0_1^+$ transition in ^{142}Xe. From the relative yields of the Mo fragments observed, the mean value of the mass of the complementary fragments associated with this transition can be deduced. The same procedure was followed for other transitions proposed in ^{142}Xe as well as for transitions proposed in ^{141}Xe (Ref. 8) and for known transitions in the lighter Xe isotopes. Figure 3(b) shows the resulting average Mo masses as a function of the known and proposed Xe masses. The smooth trend observed confirms the mass assignments for the new level sequences in ^{141}Xe and ^{142}Xe. Supporting evidence is provided by the observed yields of the Xe isotopes. These fall roughly on a curve which is Gaussian in shape with a maximum near $A=139$.

The resulting level scheme for ^{142}Xe is shown in Fig. 4. The observed excitation energy $E(2_1^+)=287.2(2)$ keV and ratio $E(4_1^+)/E(2_1^+)=2.405(4)$ can be compared with the predicted values of 300(40) keV and 2.5(1), respectively, which were discussed above. They agree with the predictions of the N_pN_n scheme within the uncertainties associated with its use. This agreement increases confidence in the use of the scheme as a predictive tool in this region, and substantiates its basic assumption that the isospin-zero interaction between valence neutrons and protons plays the major role in determining the basic properties of the low-lying levels.[4,5] The ^{142}Xe comparison emphasizes how the scheme automatically takes quantitative account of the competing factors discussed earlier: the extrapolation of existing systematics, pointing toward greater deformation for ^{142}Xe, and the approach of the $Z=50$ closed shell, pointing towards more spherical character. Since the controlling factor is the residual valence p-n interaction, the N_pN_n scheme inherently combines competing trends as a function of N and Z.

A final comment on procedures with the N_pN_n scheme may be useful. Despite the fact that predictions for unknown nuclei far from stability are often interpolative processes, it must be recognized that the scheme contains an implicit assumption. The p-n interaction is generally dominated by monopole and quadrupole components. The effect of the former is only to introduce an effective shift[9] in single-particle energies, and these shifts are the origin of the behavior of shell gaps as N and Z vary and account,[5,10] for example, for the evolution of the shape transitional regions near $A=100$ and $A=150$. The quadrupole (and higher) components of the p-n interac-

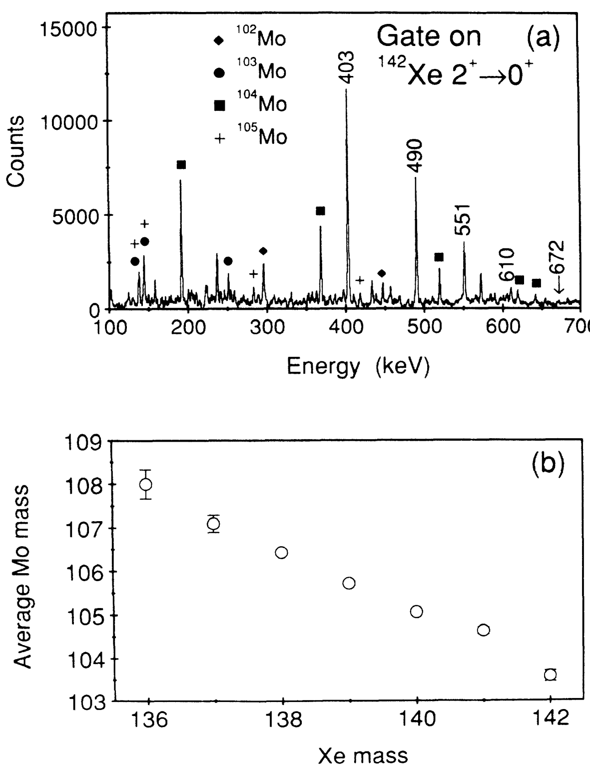

FIG. 3. (a) Ge-detector spectrum in coincidence with the peak at 287.2 keV, which is identified as the 2_1^+ to 0_1^+ transition in ^{142}Xe. Peaks are labeled with energy in keV if in ^{142}Xe, otherwise with a symbol indicating which complementary Mo fragment they arise in. (b) Average mass of complementary Mo fragments observed in coincidence with each of the Xe isotopes.

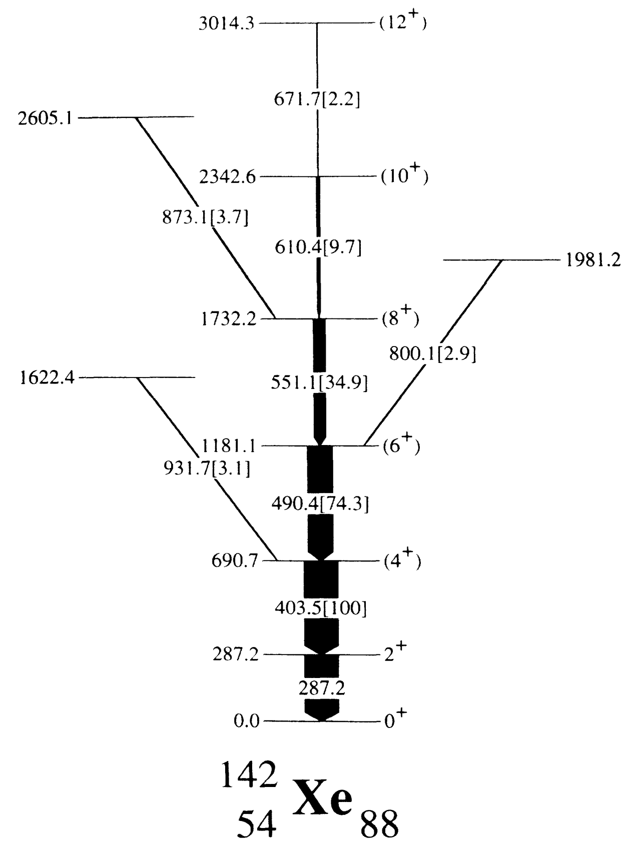

FIG. 4. The partial decay scheme determined for ^{142}Xe. Relative γ-ray intensities are given in square brackets; uncertainties in them vary from ±10% for transitions near the bottom of the bands to ±25% for transitions between weakly populated states. Errors on γ-ray energies vary from ±0.2 keV for strong lines to ±0.5 keV for weak lines.

tion act on the valence space provided by these single-particle states. The point here is that the use of the N_pN_n scheme, even in an interpolative way, can be risky if such single-particle energy shifts are sufficient to introduce or obliterate significant shell or subshell gaps that would alter the way of counting N_p or N_n for unexamined combinations of N and Z. In the case of ^{142}Xe, with $Z=54$, the status of the $Z=64$ gap is irrelevant (54 is always closer to 50 than to either 64 or 82). Moreover, the evolution of the $Z=64$ gap is well understood. In regions such as the neutron deficient Hg or Pt isotopes, however, the descent of orbitals such as the $1h_{9/2}$ proton state from across the $Z=82$ shell gap should encourage caution. It is, nevertheless, usually rather well understood in each region if such ambiguities are present and, thus, whether or not N_pN_n predictions should be reliable.

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