SIMILARITIES BETWEEN THE Sm AND Cd, EVEN-Z, EVEN-N NUCLEI AND THE SYSTEMATICS OF THE LEVEL SCHEMES OF THE INTERVENING NUCLEI*

Robert K. Smither
Argonne National Laboratory, Argonne, Illinois 60439

I will limit my talk to two central points. First, the change in the overall character of the ground-state rotational band in even-Z, even-N nuclei is a smooth function of neutron number throughout most of the periodic table. A good example of this smooth dependence is shown in fig. 1, where the energy levels of the g.s. bands in the even-Z, even-N nuclei of Sm |1-3| are plotted versus their neutron number. The neutron-rich Sm isotopes ^{158}Sm, ^{156}Sm, and ^{154}Sm all have g.s. bands typical of nuclei with a large, stable deformation. The energy of their levels is given by the simple relationship $E_L =$ $= AI(I+1)$, and their deformation changes only slightly with neutron number. Beginning with ^{152}Sm, the change becomes more rapid but remains a smooth function of neutron number. The level spacings change smoothly until we have the almost equal spacing of the quasi-rotational bands in ^{148}Sm and ^{146}Sm. It is only in the closed neutron shell nucleus ^{144}Sm that the level structure changes in a dramatic manner. The excited state rotational bands behave in much the same way as the ground-state bands. Figure 2 shows the level structure of ^{148}Sm, ^{150}Sm, and ^{152}Sm |1-3|. The spacing between the levels in a band increases with decreasing neutron number. The excitation energy of the band heads of the excited state rotational bands does not increase as fast as the level spacings in the g.s. band. This trend coupled with the fact that the spacing between the levels in the excited-state bands remains smaller than the equivalent spacing in the g.s. band leads to a

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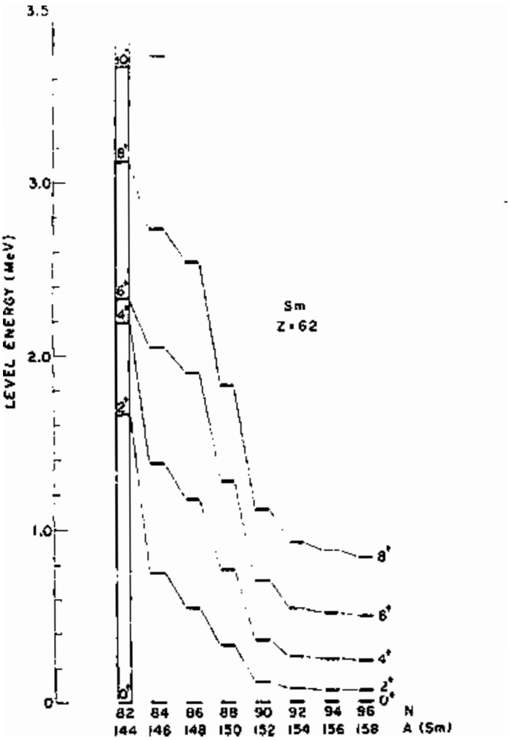

Fig.1. Energy levels of the ground-state rotational bands in the even-Z, even-N nuclei of Sm plotted versus their neutron number.

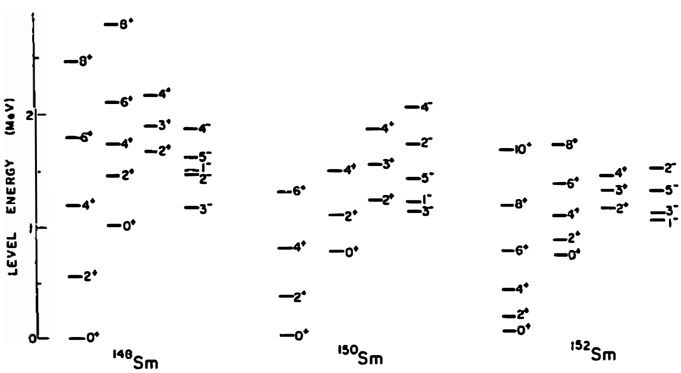

Fig.2. Level structure of ^{148}Sm, ^{150}Sm, and ^{152}Sm.

crossing of the levels of the β band (K = 0) with the g.s. band. This effect becomes more pronounced with decreasing neutron numbers so that in ^{146}Sm the 6^+ level of the excited band falls below the 6^+ level of the g.s. band. The effect is to make the gamma decay down the yrast line look like a g.s. band with back bending. It is interesting to note that this continuity in level structure is in direct contrast to what is suggested by two-nucleon transfer reactions between these nuclei |4|. The (p,t) and (t,p) reaction goes strongly to the ground state of the adjacent even-Z, even-N nuclei for all reactions between the Sm isotope except in the ^{150}Sm to ^{152}Sm reaction and the reverse. In these special cases the reaction goes strongly to the first 0^+ excited state instead of the 0^+ ground state. Some people have interpreted this as indicating a change in the character of the ground state from spherical to deformed and vice versa for the first 0^+ excited state. In light of the new data on level structure of these nuclei, I feel one should try to reinterpret the two-nucleon transfer-reactions data in terms of a subshell closure or configuration change without requiring a dramatic change in the shape of the nucleus.

The smooth change in level spacing of the g.s. bands with neutron number is continued on the other (lower neutron) side of the closed neutron shell; only now the level spacings decrease with decreasing neutron number. This can be seen in fig. 3, where the levels of the g.s. bands in the Ce nuclei |1,2| are plotted versus neutron number. Again, only at the closed neutron shell nucleus ^{140}Ce does level structure depart dramatically from a quasi-band structure. Note also that the level spacing is changing from uniform spacing of the quasi-band back toward the $E_L = AI(I+1)$ spacing of the stable rotor. This trend is continued in the Xe isotopes |1,2| shown in fig. 4. These quasi-bands are fit quite nicely by models like

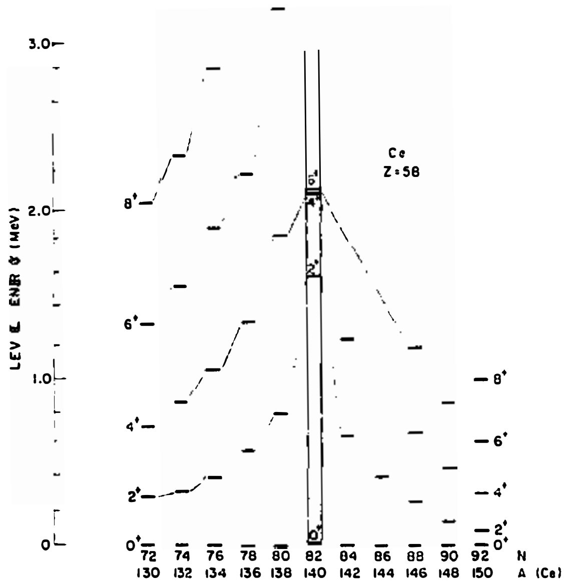

Fig.3. Energy levels of the ground-state quasi-rotational bands in the even-Z, even-N nuclei of Ce plotted versus neutron number.

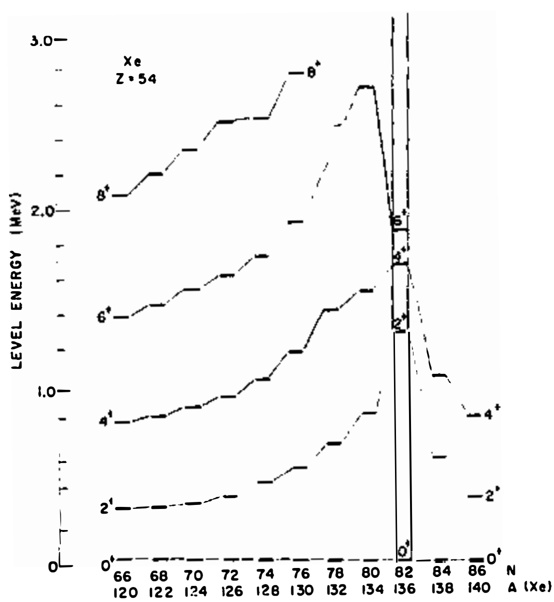

Fig.4. Energy levels of the ground-state quasi-bands in the even-Z, even-N nuclei of Xe plotted versus neutron number.

like the "Interacting Boson Model" developed by Iachello |5| and Arima (see Iachello's paper in the previous session).

The picture is similar for the Te isotopes |1,2| shown in fig. 5 except that the level structure of the nuclei near the closed neutron shell is more strongly distorted. The level scheme of ^{132}Te looks more like a closed shell configuration than that of the actual closed shell nucleus ^{134}Te. It would seem that the two extra protons (Z(Te) = 52) outside the closed proton shell at Z = 50 compensate for the two missing neutrons in ^{132}Te. The quasi-band picture with equal level spacings reasserts itself as we move away from the closed neutron shell.

Figure 6 is a similar plot for the even-Z, even-N isotopes of Cd |1,2,6|. The interesting thing here is that the Cd data almost span the whole region from the closed neutron shell at N = 50 to the closed shell at N = 82. The approximately equal spacing of the quasi-band structure persists throughout the region. Note also that the closure of the neutron subshell at N = 64 results in a change in the level spacing, but not in the overall structure. This is very reminiscent of what we saw happen in the Sm isotopes as we approach the N = 82 closed shell. This similarity is even more striking when we look at the excited-state quasi-bands as well. The level structure of the two nuclei ^{112}Cd and ^{114}Cd that fall right at the subshell closure is shown in fig. 7. The similarities in basic level structure in Cd nuclei (fig. 7) and Sm nuclei (fig. 2) even include the negative parity states. It is as if nothing had happened even though we have passed through the closed neutron shell at N = 82 and entered a quite different mass region. Once again (see fig. 7) we have the level spacing increasing with decreasing neutron number without any change in the excitation energies of the band heads or the overall level structure. As the

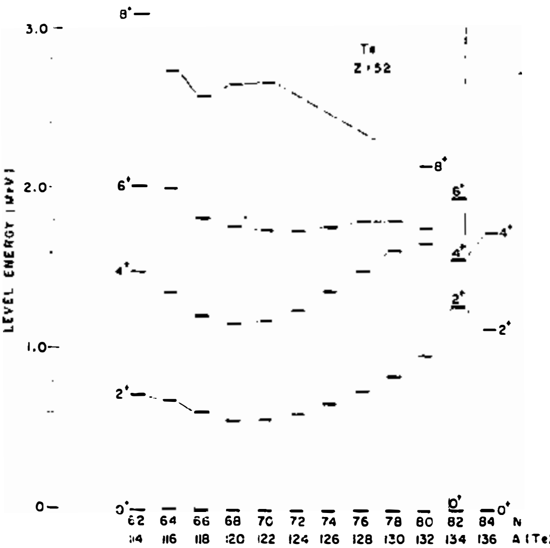

Fig.5. Energy levels of the ground-state quasi-bands in the even-Z, even-N nuclei of Te plotted versus neutron number.

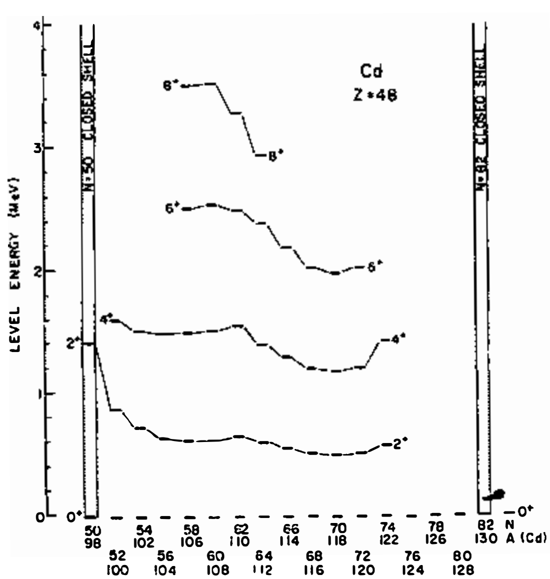

Fig.6. Energy levels of the ground-state quasi-bands in the even-Z, even-N nuclei of Cd plotted versus neutron number.

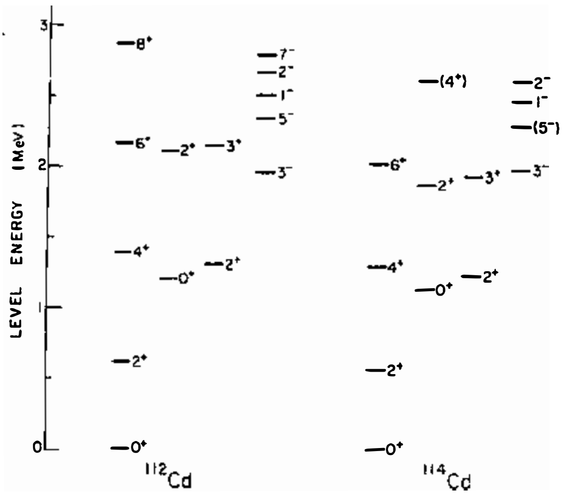

Fig.7. Level structure of ^{112}Cd and ^{114}Cd.

level spacing increases, the levels shown in fig. 2 and fig. 7 move up into a region of the level scheme that contains many other levels. The more complete level schemes of ^{112}Cd and ^{114}Cd are shown in fig. 8. It was not until the spins and parities of most of the levels were assigned and the details of the many gamma decays determined that it was possible to identify this basic structure. Also important in this work were the many (α,xn) reactions that delineated the high spin members of the quasi-bands. (Note: the 5^-, 7^-, and 9^- states as well as the 8^+ state in ^{112}Cd come from the work of Brentano; see his paper in this meeting.) Without this type of work, I do not think that people would have been willing to accept the quasi-band structure.

In summary, we have seen the similarity between the level schemes of the Sm and Cd nuclei and the smooth transition in the level schemes of the nuclei that seperate them. This brings me to my second point, and the one I wish to leave you with. I feel that, if a

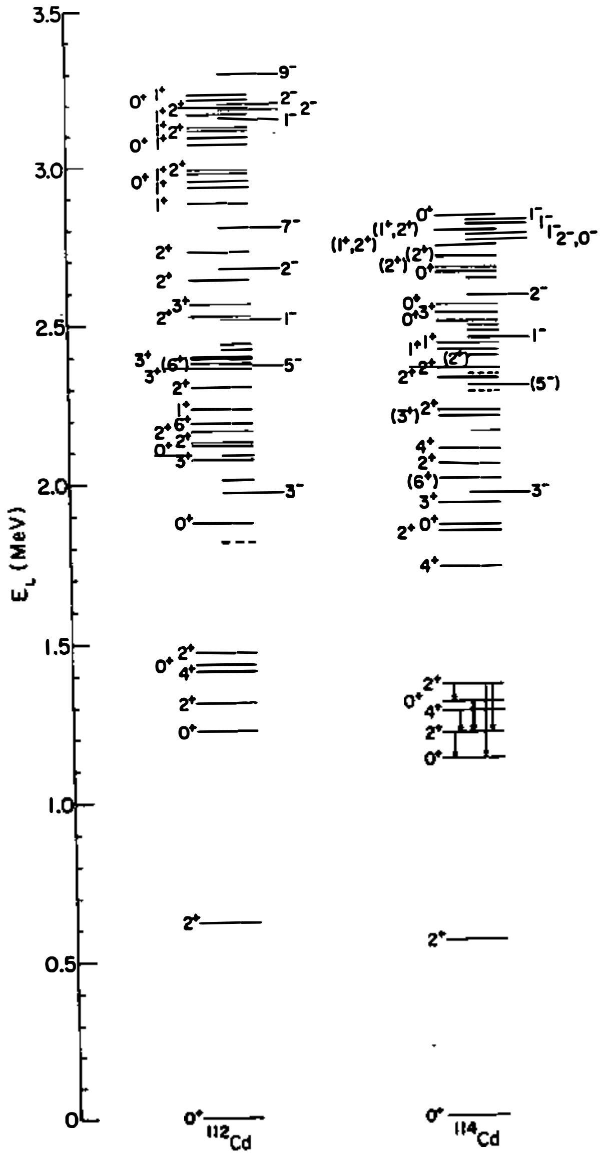

Fig.8. More complete level schemes of ^{112}Cd and ^{114}Cd.

theory is to be successful in describing these transitional and vibrational nuclei, it must be able to describe the smooth transition of the $E_L = AI(I+1)$ type rotational band into the equally spaced, $E_L \sim n\Sigma$ type quasi-band as a function of neutron number. Theories that do not accept this challenge will ultimately be found lacking.

REFERENCES

|1| A detailed list of references can be found in the "Table of Members of Quasi-Ground, Quasi-Beta and Quasi-Gamma Bands", Mitsuo Sakai, Institute for Nuclear Study Report No. INS-J-142, July 31, 1973, University of Toyko, Tokyo, Japan.

|2| Nuclear Data Sheets, Sec. B4, No. 1,2 (Academic Press, New York, May 1970).

|3| D.J. Buss and R.K. Smither, Phys. Rev. C2, 1513 (October 1970) and more recent unpublished work of R.K. Smither.

|4| P. Debenham and N.M. Hintz, Nucl. Phys. A195, 385 (1972).

|5| F. Iachello, "Collective Aspects of the Shell Model", invited paper at the International Conference on Nuclear Structure and Spectroscopy, Amsterdam, The Netherlands, September 9-13, 1974.

|6| Unpublished work of R.K. Smither.