ATOMIC MASSES ABOVE ^{146}Gd DERIVED FROM A SHELL MODEL ANALYSIS OF HIGH SPIN STATES

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Abstract

Using the extensive spectroscopic data on high spin states involving aligned valence nucleons in the very neutron deficient nuclei above ^{146}Gd we have derived the ground state masses of ^{146}Gd, ^{147,148}Tb, ^{148,149,150}Dy, ^{149,150,151}Ho, and ^{150,151,152}Er from a shell model analysis. The obtained mass values show a pronounced irregularity in the two-proton separation energies at ^{146}Gd. The results also link nine α-decay chains to the known masses.

Yrast states of moderately high spin in a region of nuclei around $^{146}_{64}Gd_{82}$ can be well described in terms of spherical shell model configurations with a few valence nucleons. The stability of the spherical shape is mainly due to the N=82 shell closure, but the single particle energy gap[1-3] at Z=64 must also be a significant contributing factor. The most direct evidence for the proton shell closure would be provided by observing a break in the masses of even nuclei across Z=64, but so far the measurements have not been extended to sufficiently proton-rich nuclei around N=82. In the present work we make detailed predictions of ground state masses for a number of nuclei in this region by exploiting relations between excitation energies for high-spin states of simple shell-model configurations. This method of relating specific excited states in neighbouring nuclei, and thereby also their ground state masses, was implemented many years ago in light nuclei by Talmi and collaborators. In heavy nuclei such complete shell model calculations are rarely feasible; however the same principles can still be applied by restricting the analysis to states dominated by a single shell model configuration. For example, it has been possible to calculate, with a precision of a few keV, the excitation energies of many aligned yrast states in the lead region[4] using the known ground state masses.

In the ^{146}Gd region where crucial ground state masses are not known, one can apply the same techniques in a reverse manner to calculate the ground state masses from the known excitation energies of selected yrast states. The well known Garvey-Kelson method, connecting nuclear ground state masses through transverse and longitudinal mass relations, is also based on the assumptions of the shell model with interacting nucleons. Our scheme is founded on the same general ideas, but it takes account of excited states also, and considers more general types of mass relations.

Many aligned yrast states involving the $\pi h_{11/2}$, $\nu f_{7/2}$ and $\nu h_{9/2}$ shell model orbitals are known in nuclei above ^{146}Gd from recent in-beam γ-ray investigations. By combining the excitation energies of 65 such high-spin levels, three known Q_α values and 7 known ground state masses, we have derived the ground state masses for the twelve nuclei shown in Fig. 1. This was done in several independent ways so that the consistency of the results could be checked. The mass uncertainties given in Fig. 1 are obtained from the

MASS EXCESSES (keV)

	82	83	84
Er	-56909(420)	-57723(280)	-60105(164)
Ho	-61040(280)	-61579(164)	-63378(83)
Dy	-67459(164)	-67547(84)	-69178(30)
Tb	-70443(83)	-70402(40)	
Gd	-75951(30)		

Fig. 1: Masses of ground states (high spin β-decay isomers) from the present analysis.

diagonal elements of the error matrix; in most cases the *relative* masses of neighbouring nuclei can be given with much better accuracy.

An examination of two-proton separation energies provides the most satisfactory test for a break in the nuclear mass surface, since complications of the odd-even staggering due to pairing can thus be avoided. Accordingly, the two proton separation energies obtained from our results are plotted in Fig. 2. A sharp discontinuity at Z=64 is obvious for the N=82 nuclei, but it is also apparent that this irregularity decreases rapidly when neutrons are added.

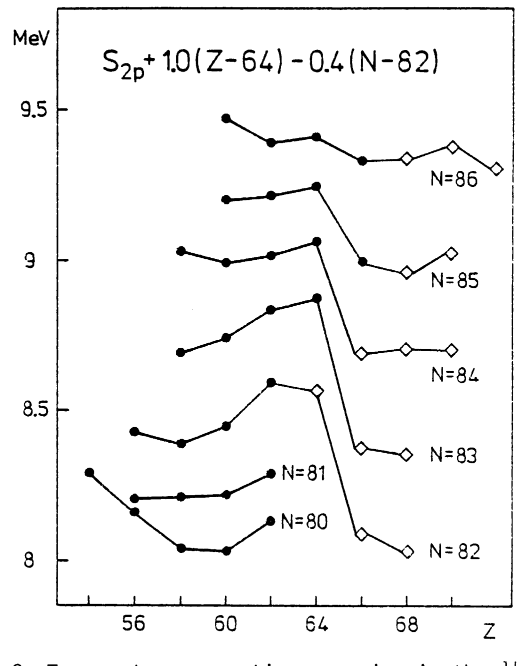

Fig. 2: Two-proton separation energies in the ^{146}Gd region from the 1977 Wapstra-Bos mass table (dots) and from the present work (diamonds).

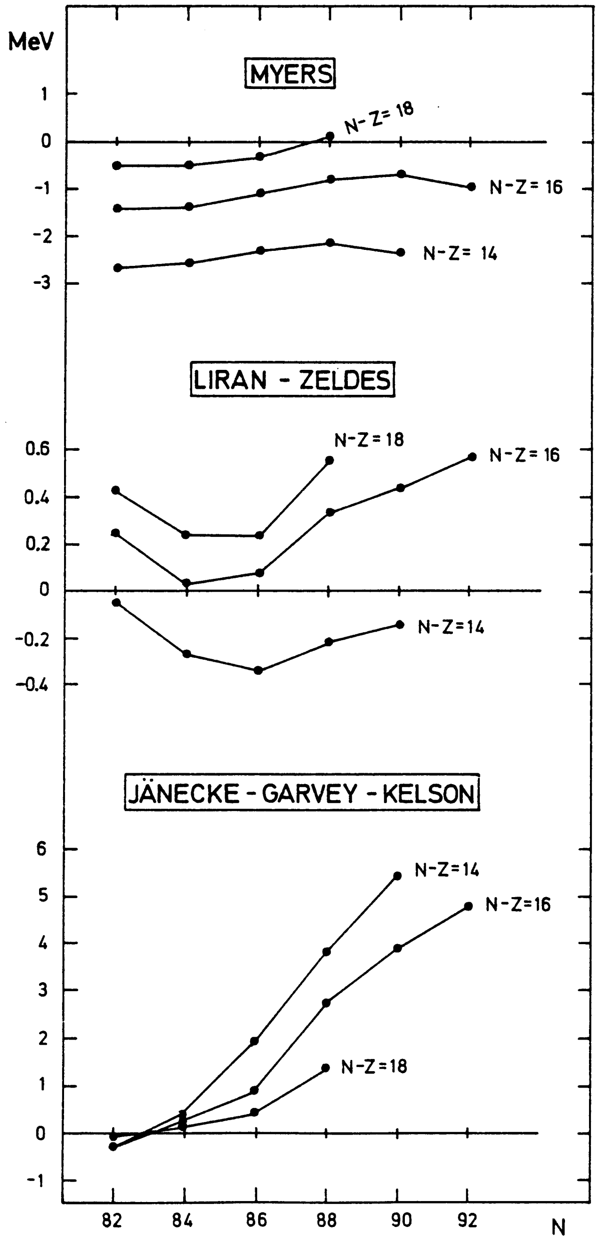

Fig. 3: Comparison with various mass formulae. The present results minus the predicted mass values are shown.

The results also link the nine α-decay chains with $14 < N-Z < 18$ to the known masses, which now provides altogether 40 new mass values. The Fig. 3 shows a comparison with various mass predictions.

References

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DISCUSSION

F. Tondeur: Your pairing calculations also give you results which can be of interest for masses; even-odd mass differences and the BCS chemical potentials λ which can be compared with the S_{2n} or S_{2p}. Do you reproduce the experimental even-odd mass differences, and how does your λ compare with S_{2n} and S_{2p}? It seems to me that your proposal of two medium-sized gaps at N = 82 and Z = 64, not very different each from the other, contrasts with the small shift in S_{2p} and large shift in S_{2n} when crossing the magic numbers Z = 64 and N = 82, respectively.

P. Kleinheinz: The principal interest in our BCS analysis was only to see whether one could reproduce the N = 82 odd proton qp energies with a set of reasonably constant single particle energies (our results are given in Styczen et al., IKP Ann. Rep. 1980, p. 51, and preprint, submitted for publication, May 1981). It certainly would be quite attractive to carry out a more exhaustive theoretical analysis which reproduces these qp energies, the proton particle-hole (and 2p2n) excitations in ^{146}Gd as well as the now available single proton and two-proton separation energies (Schmidt-Ott et al., and Blomqvist et al., these proceedings). If the resulting potential parameters are believed to also be valid for A ≈ 132, it should also reproduce the known single particle energies in ^{133}Sb [Sistemich et al., Z. Phys. A285 (1978) 305]. Equally attractive would be a similar analysis of the same four sets of experimental data on the N = 82 neutron gap in ^{146}Gd which have now become available (Pardo et al., Pipestone et al., Schmidt-Ott et al., on the masses; Styczen et al., separate contribution to these proceedings on the quasiparticle energies and neutron particle-hole excitations). We mainly do experiments to obtain such data, which keeps us rather busy. But it would be nice if you could consider to carry out such analyses.

N. Zeldes: I would like to clarify the situation in relation to the seemingly contradictory evidence concerning the proton gap above Z = 64: from the separation energies, as shown by Prof. Schmidt-Ott on Monday, and also from the excitation energies of the $h_{11/2}$ levels in Eu isotopes, the gap appears to be smaller than 1 MeV. On the other hand, Kleinheinz et al. [Z. Phys. A290 (1979) 279] claim that it is like the neutron gap above N = 82, of about 3½ MeV. However, in their paper it is stated explicitly that their gap is the gap of a proton-hole in Gd, which includes additionally to the above small proton-particle gap also the much larger proton pairing energy. Thus there is no real contradiction.

R.K. Sheline: Just a short comment. This beautiful work presents the first case (at least the first proven case) of a two-phonon octupole vibration.

V. Paar:
1. We did a systematic calculation of systematics of odd Pm (Z = 61) nuclei in the cluster-vibration model. The results are in very good agreement with experiment if one takes Z = 64 as a cloud shell. This is strong evidence that the Z = 64 closure effect persists even in Z = 61 nuclei.
2. The octupole multiplet $h_{11/2} \times 3^-$ is split much more than the octupole multiplet in ^{209}Bi, because it involves nonspin-flip matrix element $\langle h_{11/2}||Y_3||\bar{d}_{5/2}\rangle$ while in ^{209}Bi the splitting is reduced due to spin-flip matrix element $\langle h_{9/2}||Y_3||\bar{d}_{3/2}\rangle$. Thus, the large difference in splitting is a geometrical effect and not the effect of goodness of Z = 82 and Z = 64 shell closure.

P. Kleinheinz: From our comparison of the septuplet splittings we did not draw any conclusions on the relative qualities of the Z = 64 and 82 closures. We only implied (to appear in Z. Phys.) that a 0.8 MeV splitting is maybe more attractive for analysis compared to the 140 keV ^{209}Bi splitting where other small admixtures more likely could complicate the situation. I have certainly no comment on the explanation for the different magnitudes of the splittings in Bi and Tb.

C. Baktash: How much would your conclusions regarding the double-octupole phonon in ^{146}Gd change if you vary the energy of the $i_{13/2}$ neutron orbital, assumed to lie at 2.1 MeV in your calculations.

P. Kleinheinz: We would not expect a great influence of the $\nu\, i_{13/2}$ single particle energy on the energies of the two-phonon quartet in ^{146}Gd.