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Abstract: Level schemes of the very neutron-deficient isotopes ^{158}Hf and ^{162}W have been identified, and that for ^{164}W extended. Alignment of the $h_{9/2}$ neutrons is suggested.

As the neutron number approaches the closed shell at N=82, the isotopes of tungsten (Z=74) and hafnium (Z=72) should correspondingly be less deformed. Figure 1 shows the deformations predicted from the potential-energy-surface calculations of Nazarewicz, Riley and Garrett [1] and Möller and Nix [2] (combined only approximately because they are derived from different potentials). Examination of the Nilsson scheme for deformation $\beta_2 \leq 0.1$ places the neutron Fermi level at N ~ 86, close to the low-Ω orbitals of the $h_{9/2}$ neutron, and well below the $\Omega = 1/2$ orbital of the $i_{13/2}$ neutron. Since the proton Fermi level is still high in its $h_{11/2}$ shell (relative to lower-Z nuclei such as erbium), band-crossings due to competing particle alignments, for the first time in this region should favour the $h_{9/2}$ neutron. This can be seen from Figure 2 which shows the crossing frequencies calculated with the CSM for a hypothetical ^{158}Hf nucleus as a function of a fixed quadrupole deformation. A deformation $\varepsilon_2 \leq 0.1$ also corresponds to the region where the pseudo-spin partner orbitals derived from the $f_{7/2}$ and $h_{9/2}$ neutrons at sphericity, exchange character. This may be manifested as a change in signature favouring in the 1-, 2- and 3-quasiparticle bands containing these orbitals, since an $f_{7/2}$ character favours $\alpha = -1/2$, whereas $h_{9/2}$ favours $\alpha = +1/2$. These nuclei may also be susceptible to octupole effects since the neutron number N ~ 86 is optimal and quadrupole deformation is weak.

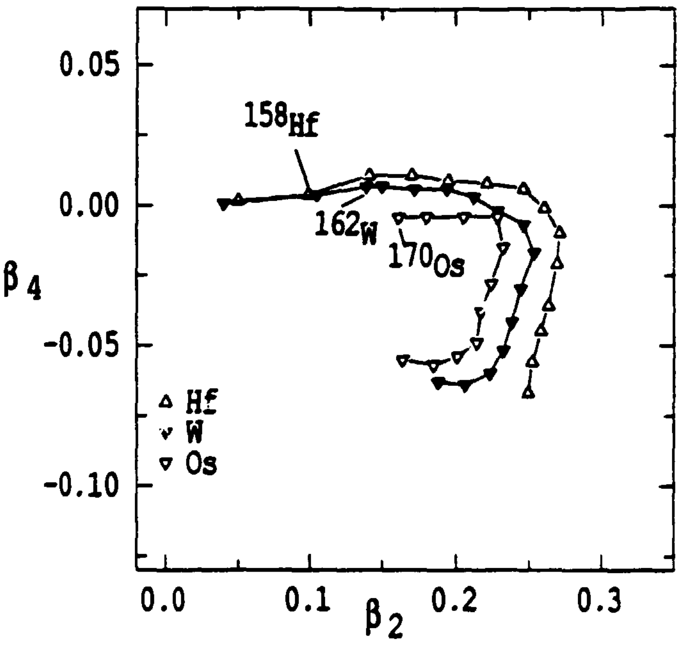

Figure 1

The lightest hafnium isotope whose level scheme is known, except for the closed shell case ^{154}Hf which was observed through the decay of a seniority isomer [3], is ^{160}Hf, studied by Murzel et al [4]. The lightest tungsten isotope previously studied is ^{164}W, whose yrast band was recently reported by Simpson et al [5].

Population of such neutron-deficient nuclei in (heavy ion, xn) reactions becomes problematic because of fission competition which reduces the residue cross-section, and because of fragmentation of the cross-section in a particular channel when charged-particle emission becomes competitive. Nevertheless, astute choice of reactions which use heavy beams near the Coulomb barrier and *involve* proton emission and also *minimises* the number of evaporated particles make some cases accessible. This tactic was recognised by the Munich [6] and Purdue/Argonne groups [7] and successfully employed in our identification of the lightest platinum and mercury isotopes known to date [8,9]. It should be remembered however, that if fission is the main limitation, level schemes extending to high spins cannot be obtained since the fission channel depletes the high ℓ-values. This limitation will be evident when new nuclei become accessible, in principle, using neutron-deficient, radioactive beams.

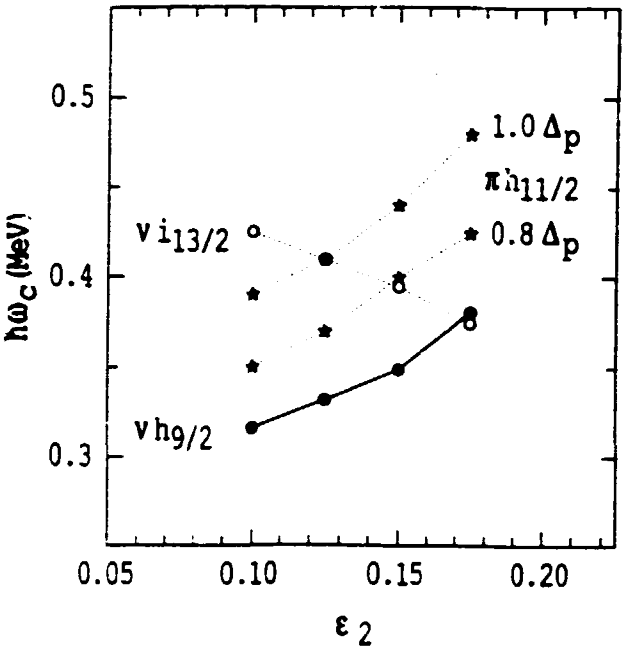

Figure 2

We have confirmed and extended the level scheme of ^{164}W using the ^{109}Ag(^{58}Ni,p2n) reaction and identified for the first time levels in ^{158}Hf (N=86) and ^{162}W (N=88) using, respectively, ^{107}Ag(^{58}Ni, p2n)^{162}W and ^{107}Ag(^{54}Fe,p2n)^{158}Hf reactions. As a by-product, level schemes were also obtained for ^{163}W and ^{159}Hf, the latter being observed in two of the bombardments. The bulk of the measurements were carried out using 253 MeV, ^{58}Ni and 233 MeV, ^{54}Fe beams from the 88-inch cyclotron (in combination with the ECR source) at the Lawrence Berkeley Laboratory. Gamma-rays were observed in the 21-detector array, HERA. Additional measurements were carried out, and are still in progress at the ANU, 14 UD Pelletron facility.

Assignment to a specific proton number was made on the basis of coincidences between the main transitions and characteristic X-rays, examples of which are shown in Figure 3. (Note that this requires minimal absorbers and due attention to time-walk for low-energy transitions.) The main products in the bombardments are the odd-odd nuclei ^{162}Ta and ^{158}Lu for which level schemes are also being constructed. X-ray coincidences in these cases are generally more intense because of the presence in the level schemes of relatively low energy MI transitions which, through their large conversion coefficients, lead to high X-ray production.

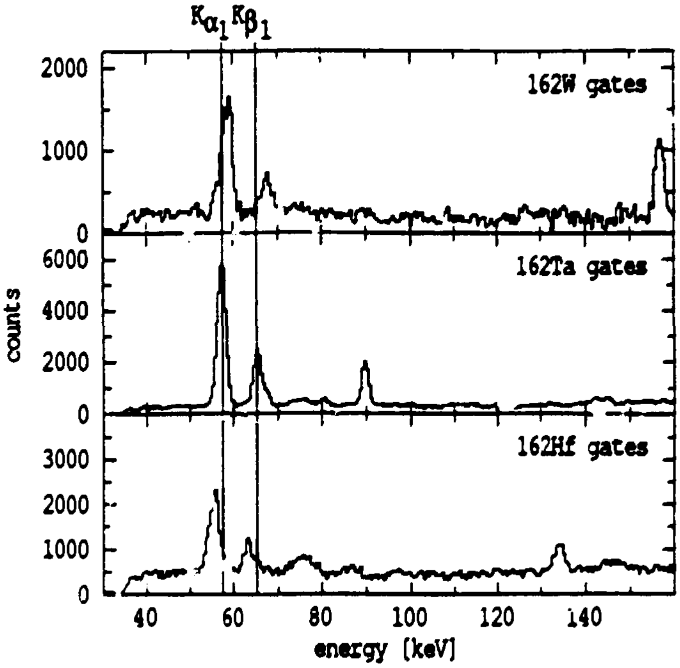

Figure 3

For ^{164}W, two sidebands which collect a substantial part of the yrast intensity, were identified. They are similar in structure to the negative parity bands known [10,11] in the isotone ^{162}Hf and presumably arise from the $\nu(h_{9/2}i_{13/2})$ (or AE and AF) configurations. These become increasingly more competitive with decreasing neutron number.

Coincidence gates on the proposed $2^+ \rightarrow 0^+$ transitions in ^{158}Hf and ^{162}W are shown in Figure 4. Neither shows a regular structure, and both overlap with transitions in identified contaminants, the products of competing channels. Preliminary schemes have been constructed for both isotopes, but there are at present ambiguities in the schemes, particularly in the ordering of transitions in the sidebands, and in the feeding connections to the low-spin yrast bands. It is expected that these will be resolved with additional measurements. A single band is observed in ^{163}W and it is assumed to be associated with the $i_{13/2}$ neutron, decoupled sequence. In ^{159}Hf, the main band populated probably arises from the $h_{9/2}$ neutron configuration.

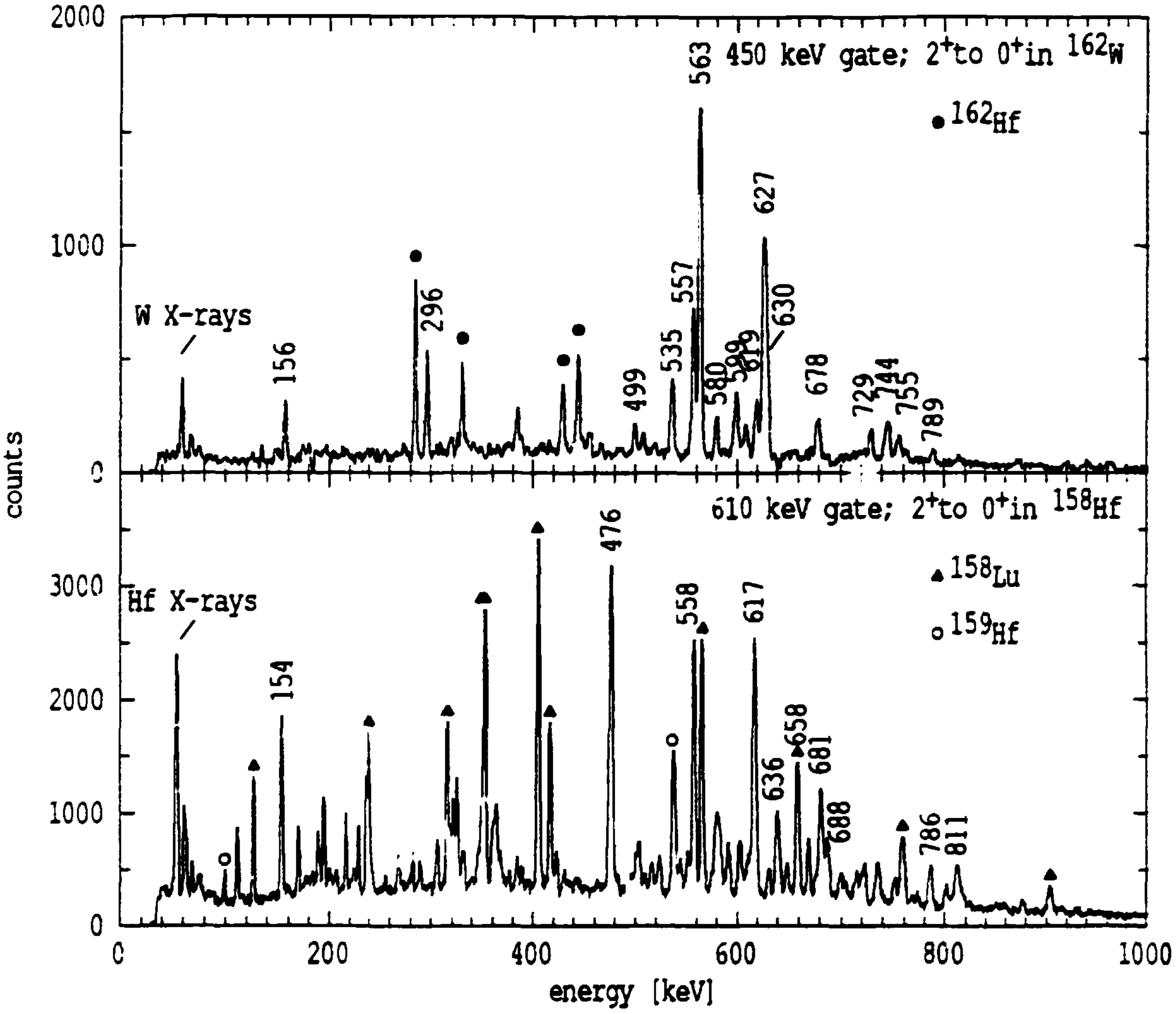

Figure 4

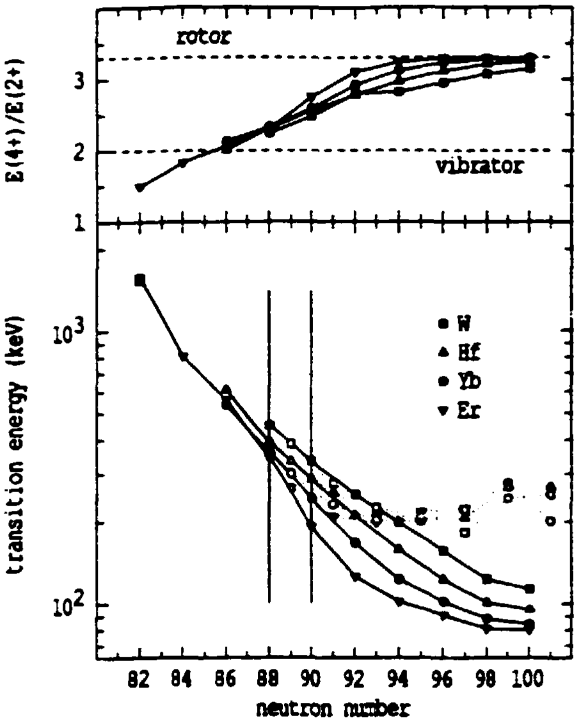

Figure 5. Open symbols represent the $17/2^+ \rightarrow 13/2^+$ transitions.

The proposed $2^+ \rightarrow 0^+$ transition energies and the E_{4^+}/E_{2^+} ratios fit smoothly into the systematics shown in Figure 5, as does the proposed $17/2^+ \rightarrow 13/2^+$ transition in ^{163}W (of energy 385 keV). The E_{4^+}/E_{2^+} ratio in ^{158}Hf is close to the vibrational limit.

Net alignments for the range of even-even and odd-N isotopes, collecting previously published data [4,5,10,11,12] and the new results on ^{164}W, ^{163}W, ^{162}W, ^{158}Hf and ^{159} Hf, are shown in Figures 6 and 7. (The same reference parameters have been used for each even-even nucleus and its A+1, odd neighbour.) The alignment gain near $\hbar\omega$=0.3 MeVin the positive parity yrast band in ^{162}W is low and similar to that in ^{160}Hf. Both are distinctly different from the ^{162}Hf and ^{164}W isotones, which show a large alignment, assigned to the $(i_{13/2})^2$ neutrons [5,10,11]. The curve for ^{158}Hf is irregular, even at low spins.

The negative-parity bands in ^{164}W show a relatively constant alignment, consistent with blocking of both $h_{9/2}$ and $i_{13/2}$ neutrons, until the beginning of a weak alignment gain near $\hbar\omega \approx 0.40$ MeV, presumably from the $(h_{11/2})^2$ protons. The $i_{13/2}$ neutron band in ^{163}W has a complex shape, compatible with alignment gains from the $h_{9/2}$ neutrons and the $h_{11/2}$ protons, in close proximity. This directly supports the proposition of Simpson et al [5], that the irregular alignment gain in ^{164}W after the major crossing due to the $(i_{13/2})^2$ neutrons is due to the same two alignments – both trajectories are similar. (This is also consistent with the prediction [2] that the deformation of ^{163}W will resemble ^{164}W rather than ^{162}W.)

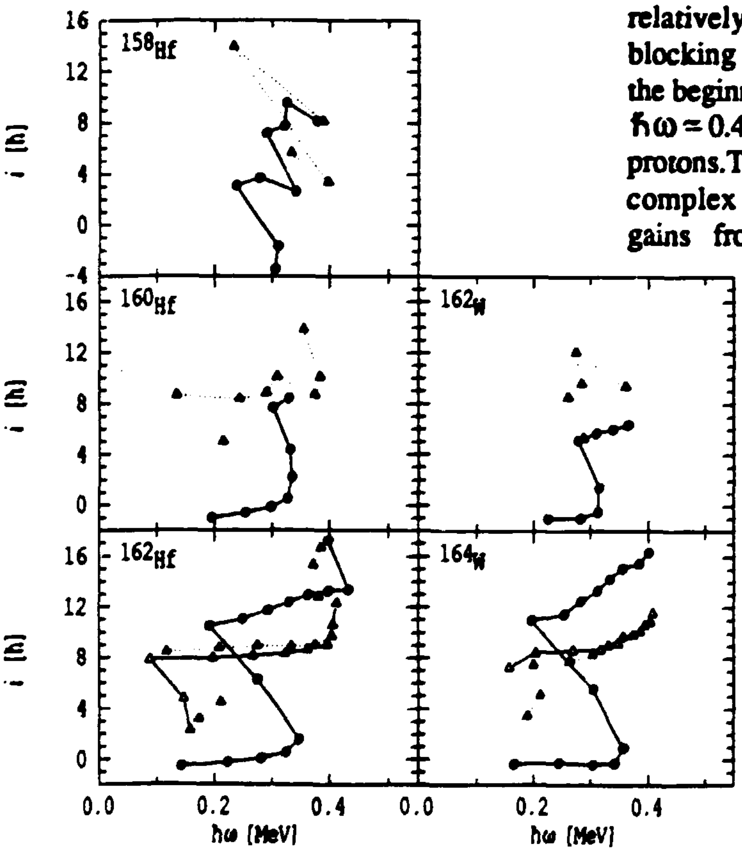

Figure 6. Net alignment in even-even isotopes (circles are positive parity states; triangles are negative parity states)

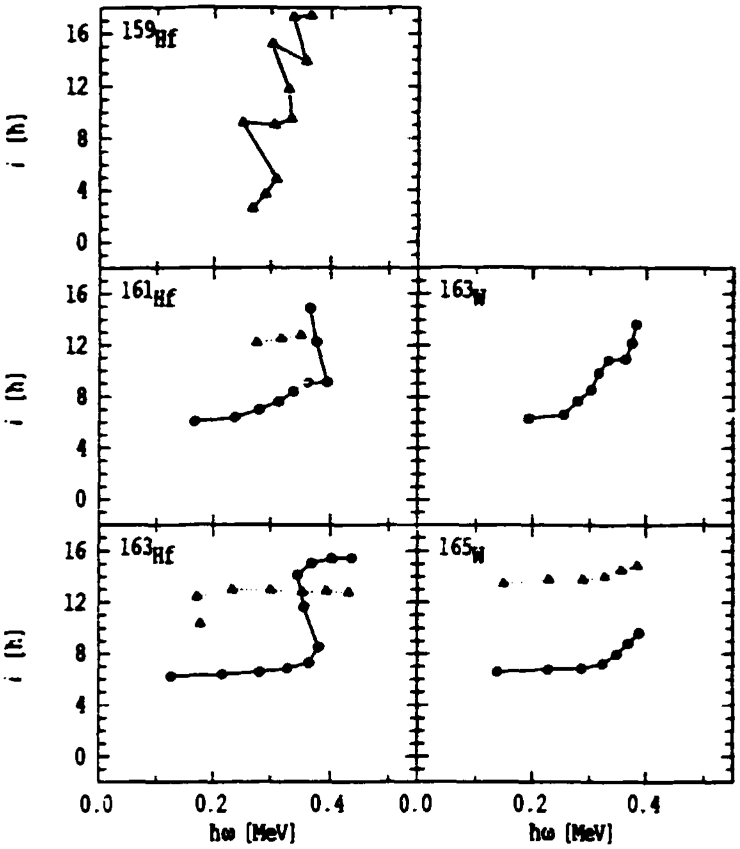

Figure 7. Net alginment in odd-neutron isotopes.

The alignment gain in the yrast band of ^{162}W is proposed to be due to the $h^2_{9/2}$ neutrons (with Δi = 7ħ) consistent in frequency and alignment with the CSM calculations. The small magnitude of the alignment gain in ^{160}Hf, attributed to $(i_{13/2})^2$ neutron in ref [4] remains problematic (as noted by those authors). No regularity is discernible in the side-band sequences, assumed to be of negative parity, in either ^{162}W or ^{158}Hf, but further analysis is necessary to confirm the spin assignments.

Characterisation of the alignment gains is also being pursued through the structure of the bands in the neighbouring odd-odd isotopes ^{158}La and ^{162}Ta, currently under evaluation.

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