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Deep inelastic reactions and isomers in neutron-rich nuclei across the perimeter of the A = 180-190 deformed region

G.D. Dracoulis[1,a], G.J. Lane[1], A.P. Byrne[1], H. Watanabe[2,7], R.O. Hughes[1,8], F.G. Kondev[3], M.P. Carpenter[4], R.V.F. Janssens[4], T.Lauritsen[4], C.J. Lister[4], D. Seweryniak[4], S. Zhu[4], P. Chowdhury[5], Y. Shi[6], and F.R. Xu[6]

[1] *Department of Nuclear Physics, RSPE, Australian National University, Canberra, ACT 0200 Australia*
[2] *RIKEN Nishina Center, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan*
[3] *Nuclear Engineering Division, Argonne National Laboratory, Argonne IL, 60439, U.S.A.*
[4] *Physics Division, Argonne National Laboratory, Argonne IL, 60439, U.S.A.*
[5] *Department of Physics, University of Massachusetts Lowell, Lowell, MA 01854, U.S.A.*
[6] *School of Physics, Peking University, Beijing 100871, China*
[7] *School of Physics and Nuclear Energy Engineering, Beihang University, Beihang 100191, China*
[8] *Dept of Physics, University of Richmond, 28 Westhampton Way, Richmond, VA 23173, USA*

Abstract. Recent results on high-spin isomers populated in deep-inelastic reactions in the transitional tungsten-osmium region are outlined with a focus on ^{190}Os, ^{192}Os and ^{194}Os. As well as the characterization of several two-quasinutron isomers, the 12^+ and 20^+ isomers in ^{192}Os are interpreted as manifestations of maximal rotation alignment within the neutron $i_{13/2}$ and possibly proton $h_{11/2}$ shells at oblate deformation.

1 Introduction

The region of deformed nuclei near Z = 72 and N = 104 is prolific in multi-quasiparticle high-K isomers, formed by combining high-Ω orbitals near the proton and neutron Fermi surfaces. More are expected to occur in the more neutron-rich isotopes but few of these are accessible by conventional fusion-evaporation reactions. As reviewed recently [1], multi-nucleon transfer or "deep-inelastic" reactions with heavy energetic beams offer an alternative, although non-selective, means of production, complementing the broader reach of fragmentation reactions. We have carried out a series of deep-inelastic studies that extend into the transitional region of neutron-rich W, Ir, Os and Au isotopes where static and dynamic triaxial-, oblate- and prolate-deformed structures are expected to compete. Some of our results obtained for these isotopes have been reported recently [2–6].

2 Experiments with deep-inelastic and transfer reactions

Figure 1 is a snapshot of the nuclei in this region where new isomers have been identified and characterized. With the current experimental capabilities, in general it is possible to extend to about four neutrons beyond stability. Measurements were made using 6 MeV per nucleon, pulsed and chopped

[a] e-mail: george.dracoulis@anu.edu.au

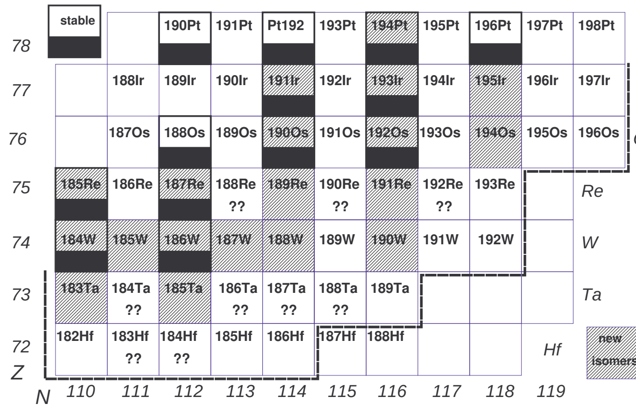

Figure 1. Approximate reach (dashed line) of deep-inelastic reactions with current detector sensitivities in the well-deformed region [1]. Nuclei in which new isomers have been identified or significant information on existing isomers obtained are indicated by the hatching. Question marks indicate cases currently under evaluation.

^{136}Xe beams from the ATLAS facility at Argonne National Laboratory, incident on a range of enriched targets including ^{186}W, ^{187}Re and ^{192}Os. Gamma-rays were detected with Gammasphere with about 100 detectors in operation. Experimental details and analysis techniques including time-correlations to construct the level schemes and γ-γ-correlations to aid in spin assignments can be found in [2–7].

3 Os isotopes

Some representative γ-ray coincidence spectra produced with double gates and different time regions with respect to the beam pulses, are given in Fig. 2. Figure 2(a) produced from a sum of double

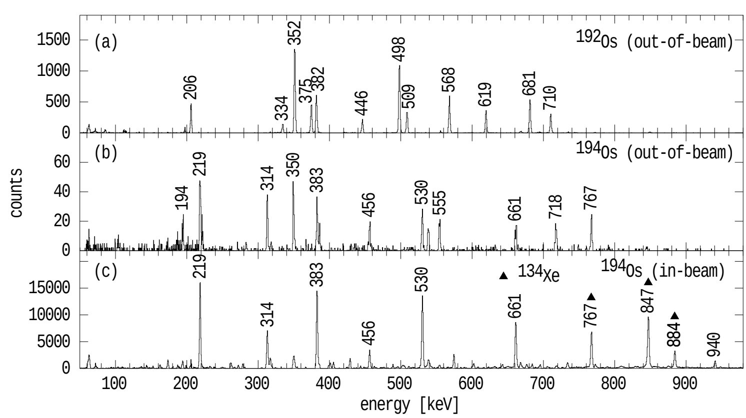

Figure 2. Selected γ-ray coincidence spectra in ^{192}Os and ^{194}Os with prompt (in-beam) and delayed (out-of-beam) time conditions.

gates on the transitions directly below the 20^+, 295 ns isomer exposes the strong 352-keV and 498-keV transitions which lead, in cascade, to the bandhead of the long-lived 10^- isomer. These are not observed in gates on decays from the lower-spin yrast states [3]. Figure 2(b) shows part of the evidence for a high-lying isomer in ^{194}Os [4], while double gates on the lower-lying yrast transitions during the beam pulse give the spectrum of Fig.2(c). This clearly shows the transitions in the main complementary partner, ^{134}Xe, produced from the removal of two neutrons from the ^{136}Xe beam. (Space considerations preclude reproducing detailed level schemes here. See, instead, Refs. [3, 4]).

4 Interpretation

The net alignments of the band structures in the even-even isotopes are illustrated in figure 3. These

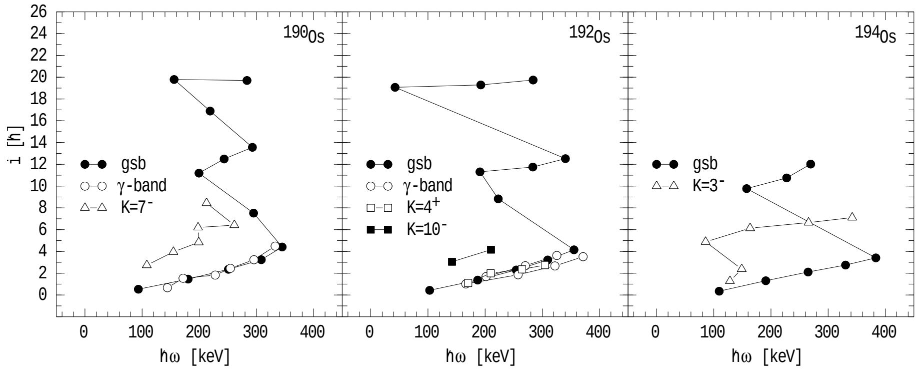

Figure 3. Net alignments for bands in ^{190}Os, ^{192}Os ^{194}Os obtained with a common reference.

have been evaluated using a reference with a lower moment-of-inertia than would be used for a prolate deformation, as is appropriate for oblate rotation. Because of this, the low-frequency trajectories of the ground and γ bands in each case have a small (artificial) upward slope. This is also the case for the other bands, such as the $K^{\pi} = 4^{+}$ band in ^{192}Os. The newly identified 10^{-} band shows about $3\hbar$ more alignment, consistent with the presence of the $11/2^{+}[615]$, $i_{13/2}$ neutron orbital in its configuration. As discussed in Ref. [3] there are two sharp increments in the yrast sequence of ^{192}Os, beginning near the 12^{+} and 20^{+} states, both of which are isomeric, corresponding to alignment gains of $\sim 12\hbar$ and $\sim 8\hbar$ respectively. (The results for ^{190}Os are similar but at this stage, less well defined.)

The first alignment in ^{192}Os was attributed in Ref. [3] to the AB alignment expected for the $i_{13/2}$ neutron shell when the Fermi level is close to the low-Ω orbitals, as is the case for oblate deformation and predicted for the ^{192}Os case in Ref. [8]. The second corresponds to either alignment of the BC neutrons, or possibly the ab protons[1]. (Although various intrinsic states are predicted by the calculations in the energy region of the 20^{+} isomer, the structures observed do not have the associated rotational bands that would be expected if they were high-K states.) The alignment gains are in fact, similar to those observed in the $N = 116$ isotones , ^{194}Pt and ^{196}Hg [3]. At the first alignment, short-lived 12^{+} isomers resulting from low-energy $E2$ transitions with enhanced strengths ($\sim$ 2-10 W.u.) occur in both ^{194}Pt and ^{196}Hg [10], comparable to the strength of decay from the isomer in ^{192}Os

Therefore, the current conclusion is that the observed 20^{+}, 295-ns and 12^{+}, 2-ns isomers in ^{192}Os are products of alignment gains at oblate deformation. The dynamical effects and deformation changes supporting this conclusion are contained implicitly in the Total Routhian Surface (TRS) results given in Fig. 4 (from [3]). The ground-state configuration is associated with a soft prolate deformation at

[1]The nomenclature used is A, B, C... for neutrons near the Fermi surface and a, b, c... for protons (cf. Ref.[9]).

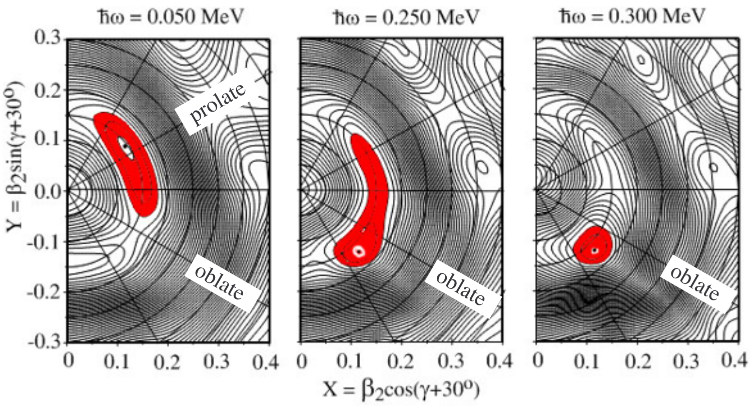

Figure 4. Total Routhian surfaces for ^{192}Os at the frequencies indicated with a contour separation of 200 keV.

low frequency (left panel) while the change towards oblate deformation (minimum at γ = -76^o) is associated with about 12$\hbar$ of alignment from neutrons (middle panel). At higher frequencies, the deformation is similar but more localised (right-hand panel). However, from the wave functions, the total aligned angular momentum now has a component of about 10$\hbar$ from the protons, indicating that the second alignment could be from the *ab* protons rather than the next pair of $i_{13/2}$ neutrons (*CD*).

5 Outstanding issues

Configuration-constrained potential-energy-surface calculations also predict that other prolate and triaxial multi-quasiparticle structures should exist [3]. In particular, the favored K^π = 12$^+$ two-neutron configuration, 11/2$^+$[615]⊗13/2$^+$[606], is expected to fall rapidly in energy with neutron number and lead to low-lying intrinsic states, so low in ^{194}Os, for example, as to be forced to β decay. The 12$^+$ configuration coupled to a $\nu^2$3/2$^-$[512]⊗9/2$^-$[505] component is predicted to lead in a similar way to low-lying 18$^+$, high-*K* states. The isomer in ^{194}Os is a candidate for one of these.

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