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# Discovery of $^{157}$W and $^{161}$Os

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## ABSTRACT

The nuclides $^{157}$W and $^{161}$Os have been discovered in reactions of $^{58}$Ni ion beams with a $^{106}$Cd target. The $^{161}$Os $\alpha$-decay energy and half-life were $6890 \pm 12$ keV and $640 \pm 60$ µs. The daughter $^{157}$W nuclei $\beta$-decayed with a half-life of $275 \pm 40$ ms, populating both low-lying $\alpha$-decaying states in $^{157}$Ta, which is consistent with a $7/2^-$ ground state in $^{157}$W. Fine structure observed in the $\alpha$ decay of $^{161}$Os places the lowest excited state in $^{157}$W with $I^\pi = 9/2^-$ at $318 \pm 30$ keV. The branching ratio of $5.5^{+3.1}_{-2.2}\%$ indicates that $^{161}$Os also has a $7/2^-$ ground state. Shell-model calculations analysing the effects of monopole shifts and a tensor force on the relative energies of $2f_{7/2}$ and $1h_{9/2}$ neutron states in $N = 83$ isotones are presented.

The study of nuclei far from the line of $\beta$ stability has revealed significant modifications of single-particle energies. It has been shown that the presence of a tensor component in the nucleon–nucleon effective interaction is important for understanding the shell structure of neutron-rich nuclei. This gives rise to particular shifts in the relative energies of specific orbitals, depending on their occupancy [1,2]. This tensor term most probably plays a significant role in determining the structure of much heavier nuclei [3,4], as revealed through the evolution of the relative energies of single-particle levels in isotopic or isotonic chains of nuclei at closed shells [5]. In this work, focusing on the region at the proton drip line above $N = 82$, the structure of nuclei is governed at low spin and excitation energy by valence neutrons in the $2f_{7/2}$ and $1h_{9/2}$ orbitals and protons in the $3s_{1/2}$, $2d_{3/2}$ and $1h_{11/2}$

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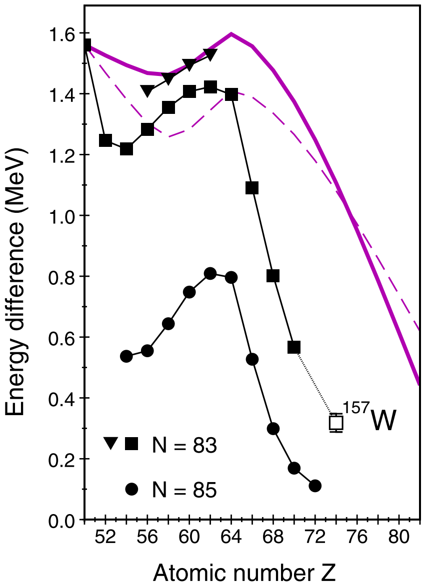

**Fig. 1.** (Colour online.) The triangles show energy differences measured from transfer reactions on stable nuclei of the centroid energies determined for the $2f_{7/2}$ and $1h_{9/2}$ neutron single-particle orbitals for N = 83 isotones, while energy differences between the lowest-lying $7/2^-$ and $9/2^-$ states for N = 83 and N = 85 isotones are shown by the squares and circles, respectively. The open square shows the value for $^{157}$W from this work. Data are taken from [7,9]. Comparison of data for N = 83 isotones with shell model calculations of the $\nu 1h_{9/2}$–$\nu 2f_{7/2}$ energy difference with (thick line) and without (dashed line) the added tensor force. The calculations are normalized to the value for $^{133}_{50}Sn_{83}$.

orbitals [6]. In particular, one expects the proton–neutron tensor force component acting between protons filling the $1h_{11/2}$ orbital and a single neutron in the $1h_{9/2}$ or $2f_{7/2}$ orbitals to modify their relative single-particle energies in a specific way that differs from the changes arising only from a central force.

The excitation energies and spectroscopic factors of $9/2^-$ states in the stable N = 83 isotones $^{139}_{56}$Ba, $^{141}_{58}$Ce, $^{143}_{60}$Nd and $^{145}_{62}$Sm were recently measured using transfer reactions [7]. This allowed the centroid energy of the $\nu 1h_{9/2}$ orbital relative to the $\nu 2f_{7/2}$ orbital to be deduced in these nuclei, see Fig. 1. Above Z = 64, the occupation probability of the $\pi 1h_{11/2}$ orbital increases with increasing Z and the energy difference between the $\nu 2f_{7/2}$ and $\nu 1h_{9/2}$ orbitals is expected to drop rapidly. Unfortunately, the heavier isotones required to extend these systematics above Z = 64 are all unstable, rendering the measurement of spectrosopic factors and thus of the single-particle content for these states impossible at present. However, the measured energy differences between the lowest-lying $9/2^-$ and $7/2^-$ states for the N = 83 and N = 85 isotones plotted in Fig. 1 do indeed show a rapid drop above Z = 64. Although caution should be exercised in case there is significant fragmentation of single-particle strength in nuclei when moving away from stability, the measured spectroscopic factors for both $7/2^-$ and $9/2^-$ levels for $Z \leqslant 64$ [7,8] suggest this drop is reflecting the gradual approach in energy of the $1h_{9/2}$ and $2f_{7/2}$ neutron single-particle orbitals. The steep slope for these heavy N = 83 isotones suggests that the energies of the neutron single-particle orbitals may even become inverted for high Z. New experimental data for nuclei above Z = 70 are necessary to provide a definitive answer on this possibility.

In this Letter we present the discoveries of $^{161}_{76}Os_{85}$ and $^{157}_{74}W_{83}$, which have 23 fewer neutrons than their lightest stable isotopes. The experiment was performed at the Accelerator Laboratory of the University of Jyväskylä. The $^{161}$Os nuclei were populated in the $^{106}$Cd($^{58}$Ni, 3n) reaction. The target was a 1.1 mg/cm$^2$ thick, self-supporting $^{106}$Cd foil of 96.5% isotopic enrichment. Average beam currents were 2.3 particle nA for 104 hours at 290 MeV, 4.7 particle nA for 75 hours at 300 MeV and 3.0 particle nA for 96 hours at 310 MeV. The gas-filled separator RITU [10] transported the reaction products to the GREAT spectrometer [11]. $\alpha$-decay spectroscopy was facilitated by two adjacent double-sided silicon strip detectors (DSSDs) into which the reaction products were implanted. The DSSDs had an active area of 60 mm × 40 mm and a thickness of 300 μm. The strip pitch of 1 mm gave a total of 4800 independent pixels, which made it possible to correlate decays occurring within a few seconds of each other. All detector signals were passed to the triggerless data acquisition system [12], which time stamped them with a precision of 10 ns, allowing temporal correlations to be analysed using the GRAIN software package [13].

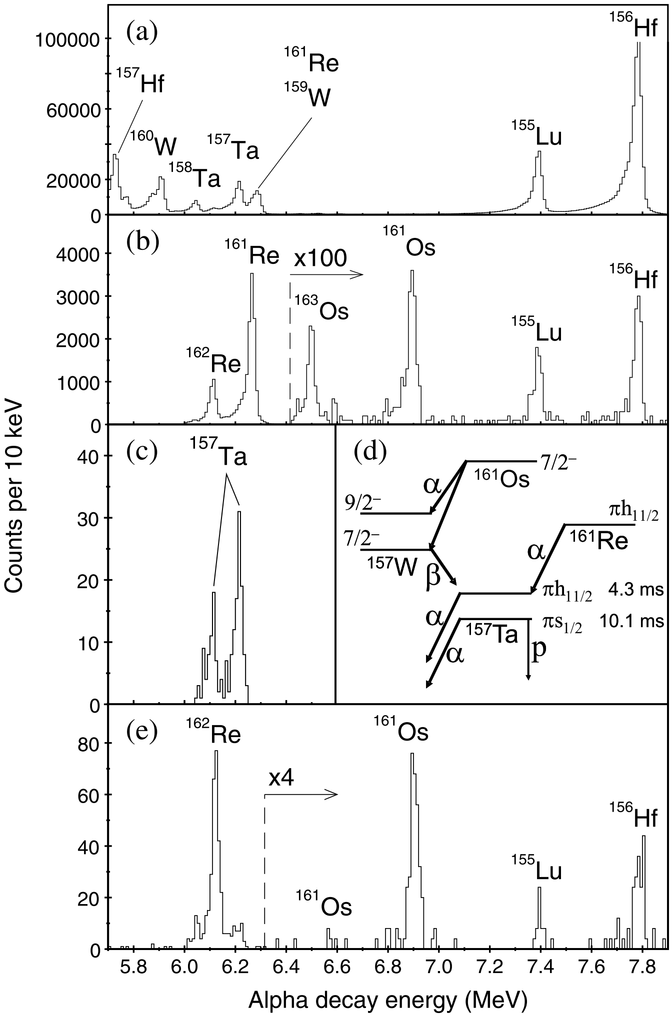

**Fig. 2.** (a) Spectrum of $\alpha$ decays occurring within 4 ms of an ion implantation into the same DSSD pixel. (b) As (a), but with the additional requirement that the $\alpha$ decay is followed within 4 s by either of the $\alpha$-decay branches of $^{157}$Ta [15]. (c) Spectrum of $^{157}$Ta $\alpha$ decays following $\alpha$ decays in the $^{161}$Os peak. (d) Decay scheme of $^{161}$Os and related nuclei. The spin and parity assignments for the states in $^{161}$Os and $^{157}$W are from the present work. (e) Spectrum of $\alpha$ decays occurring between 250 μs and 1.5 ms after an ion implantation into the same DSSD pixel that are followed between 70 ms and 1.5 s later by either of the $\alpha$-decay branches of $^{157}$Ta.

The lightest known osmium isotopes are short-lived nuclei and decay predominantly by $\alpha$-particle emission [14]. In order to isolate $\alpha$ decays of $^{161}$Os from the large number of counts in the $\alpha$-decay energy spectrum of Fig. 2(a), correlations were sought with the $\alpha$ decays of $^{157}$Ta, populated via the $\beta$ decay of $^{157}$W, see