High-Spin States Populated in Deep-Inelastic Reactions

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High spin states in the neutron rich ^{188}Os and ^{190}Os nuclei have been populated using the ^{82}Se + ^{192}Os deep-inelastic reaction. The level schemes are extended up to spin $I \approx 21$. The observed new structures are tentatively interpreted as fragments of rotational bands built on multi-quasiparticle configurations.

1 Introduction

Fusion-evaporation reactions provide the standard mechanism to populate states with high angular momentum. However, by using stable beam–target combinations beta–stable and neutron–rich nuclei cannot be studied. Neutron–rich nuclei with mass A<150 can be studied in spontaneous and induced fission. Projectile fragmentation has proven to be an efficient method of populating nuclei far from the valley of stability. However, in the case of heavy nuclei this method is still limited to species with isomeric states, needed to enhance the sensitvity of the technique (see for example [1]). Deep–inelastic reactions are the most general reaction mechanism which can be used to study neutron–rich nuclei and are able to populate relatively high–spin states.

We used the ^{82}Se+^{192}Os binary reaction to study nuclei both in the vicinity of the ^{82}Se beam and ^{192}Os target. The study of nuclei around the N=50 shell closure has given new experimental indications about the persistence of this shell gap down to Z=32 [2]. The structure of nuclei in the $A \approx$180–190 region is characterized by the presence of high-angular momentum intrinsic, i.e. noncollective, states. Such states compete with the collective excitations because the proton and neutron Fermi levels are among orbitals with large angular-momentum projections (Ω) on the symmetry axis, allowing states with large values of $K = \Sigma\Omega$ to be formed [3]. As part of a systematic study of the mass A$\approx$180–190 nuclei, some new results on the stable ^{188,190}Os nuclei, obtained by using binary reactions, are presented in this paper.

2 Experiment

Excited states in the vicinity of both the ^{82}Se beam and the ^{192}Os target nuclei have been populated using heavy-ion multi-nucleon transfer reactions and studied through γ-ray spectroscopy in a "thick target" [4] measurement. The combination of the Tandem-XTU and the superconducting LINAC ALPI accelerators at the Laboratori Nazionali di Legnaro, Italy, was used to accelerate a beam of ^{82}Se ions to an energy of 460 MeV. The ^{192}Os target, isotopically enriched to 99.0%, had a thickness of 50 mg/cm^2 on a 0.2 mm Ta backing, which is sufficient to stop all reaction fragments. High fold γ-γ coincidences were acquired with the 4π spectrometer GASP [5] consisting of 40 Compton-suppressed, large-volume germanium detectors with an inner BGO ball
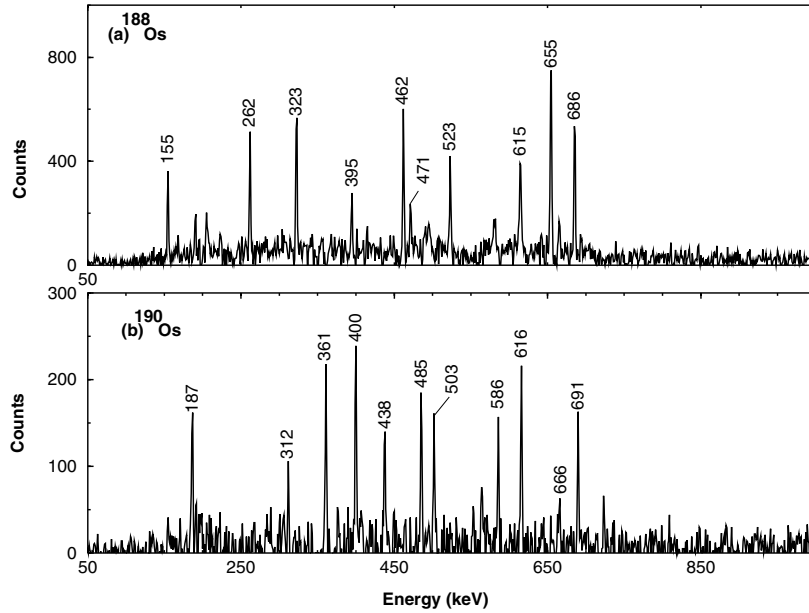
Figure 1. Double gated coincidence spectra for ^{188,190}Os. (a) In ^{188}Os the gates are on the (155, 323, 462 keV) & 574 keV transitions. (b) In ^{190}Os the gates are on the (187, 361, 503 keV) & 589 keV transitions.

acting as a multiplicity filter and a total-energy spectrometer. Events were collected on tape during five days of beam time under the conditions that a minimum of three Compton-suppressed Ge detectors and two BGO elements from the multiplicity filter fired in coincidence. With a beam current of 1 particle-nA, the event rate was ≈4 kHz and the singles rate in the germanium detectors ≈12 kHz. With such a setup γ-rays from the deexciting target-like and projectile-like fragments were detected. After gain matching for all the detectors, the coincidence data were sorted into fully symmetrized matrices and cubes for off-line analysis. Since all recoiling fragments were stopped in the target, Doppler broadening prevented the observation of transitions deexciting short-lived states and only the γ decay with lifetimes longer than the slowing-down time of the recoiling nuclei ($\approx$ 1ps) could be studied. Thus, no Doppler correction was necessary when sorting the data.

3   Results

Two- and three-dimensional γ matrices were used to construct the level schemes of ^{188,190}Os. Typical coincidence spectra are shown in Fig. 1. Partial level schemes of ^{188}Os and ^{190}Os, together with the lighter ^{184,186}Os isotopes [6, 7], are presented in Fig. 2.

In ^{188}Os the levels up to spin 10^+ of the ground state band are well established [8, 9, 10] and were confirmed in

the present experiment. C.Y. Wu *et al.* [9] reported two transitions, with energies of 699 keV and 760 keV, populating the yrast 10^+ state in Coulomb excitation. We did not observe these transitions. Instead, we confirm the existence of the 686 keV transition, previously reported by R.A. Warner *et al.* [11]. The levels above the 12^+ state are seen in this experiment for the first time. The properties of the gamma ray transitions belonging to ^{188}Os are summarized in Table I.

TABLE I: γ-ray transition energies, relative intensities and level assignments in ^{188}Os.

E_γ (keV)	I_γ (rel.)	$I_i^{\pi\,a)}$	$I_f^{\pi\;a)}$
655	1000(80)	10^+	8^+
686	710(48)	12^+	10^+
615	531(45)	14^+	12^+
523	384(38)	16^+	14^+
262	274(26)	18^+	16^+
395	243(40)	19^+	18^+
471	240(44)	20^+	19^+
495	182(64)	21^+	20^+

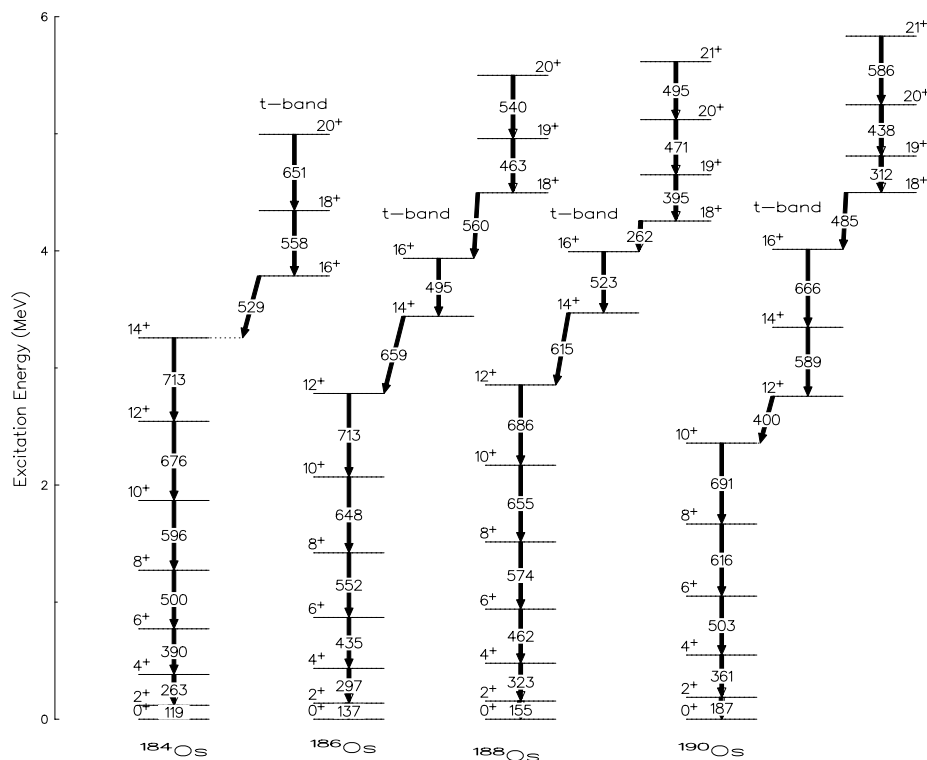$^{a)}$ The spin-parity values are tentative. They are based on comparison with the lighter osmium isotopes.

Figure 2. Positive parity yrast structures of ^{184,186,188,190}Os nuclei. The high spin states in ^{188,190}Os are from the present work. The spin-parity and configuration assignmenst are tentative and based on comparison with ^{184,186}Os [6, 7]. For alternative configuration assignments see the text.

In ^{190}Os the levels up to spin 10^+ of the ground state band are known from earlier works [9, 10, 12]. Here again we did not see the 769 keV and 654 keV γ-ray transitions populating the 10^+ state, as proposed by C.Y. Wu *et al.* [9]. Levels above the 10^+ state are seen for the first time in the present work. The properties of the gamma ray transitions belonging to ^{190}Os are summarized in Table II.

TABLE II. γ-ray transition energies, relative intensities and level assignments in ^{188}Os.

E_γ (keV)	I_γ (rel.)	$I_i^{\pi\,a)}$	$I_f^{\pi\ a)}$
400	100(12)	12^+	10^+
589	96(10)	14^+	12^+
666	96(7)	16^+	14^+
485	88(12)	18^+	16^+
312	45(9)	19^+	18^+
438	64(10)	20^+	19^+
586	59(8)	21^+	20^+

$^{a)}$ The spin-parity values are tentative. They are based on comparison with the lighter osmium isotopes.

4   Discussion

As first step of the configuration assignment we compare the new structures observed in ^{188,190}Os with the lighter isotopes (see fig.2), where more experimental data are available. In both ^{184,186}Os the groundstate band is crossed by a so-called t-band, based on the two-neutron $\nu 11/2^+[615]9/2^+[624]$ configuration. The assignments were based on experimentally determined branching ratios, lifetimes of the $K^\pi=10^+$ bandheads, and comparison with blocked BCS calculations [6, 7]. The yrast 18^+ state in ^{186}Os was interpreted as a $K^\pi=18^+$ four neutron $\nu 11/2^+[615]9/2^+[624]9/2^-[505]7/2^-[503]$ state. Based on the similarities between the yrast structures of the osmium isotopes, we propose that the 14^+ and 16^+ states in ^{188}Os, and 12^+, 14^+, 16^+ states in ^{190}Os are members of the two-neutron $\nu 11/2^+[615]9/2^+[624]$ band. In the same way the states with spin-parity 18^+, 19^+, 20^+, 21^+ may have the four neutron $\nu 11/2^+[615]9/2^+[624]9/2^-[505]7/2^-[503]$ configuration.

In order to verify whether the assignment based on systematics is reasonable, multi-quasiparticle calculations [13] have been performed using blocked BCS pairing without residual interaction. According to the calculations the $K^\pi=9^-$ $\nu 11/2^+[615]7/2^-[503]$ intrinsic state is ≈ 800 keV below the $K^\pi=10^+$ $\nu 11/2^+[615]9/2^+[624]$ state, both in

^{188}Os and ^{190}Os nuclei. However, the lack of observation of low energy dipole transitions favours the K$^\pi$=10$^+$ assignment. Furthermore, the 9$^-$ bandhead decay is expected to be isomeric, and may be too long lived to be seen in the present analysis,

We couldn't establish the level scheme of ^{192}Os up to high spins, although its excited states must have been populated with high cross sections. This might be explained by the existence of a K$^\pi$=10$^-$ $T_{1/2}$=5.9 s yrast isomer at 2015 keV excitation energy, interpreted as having the ν11/2$^+$[615]9/2$^-$[505] configuration. However, a similar yrast isomer with $T_{1/2}$=9.9 min at 1705 keV exists also in ^{190}Os [14]. It seems that in ^{192}Os the high spin states decay via the long-lived isomer, whereas in ^{190}Os the situation is different.

The data analysis is still in progress. Therefore, new experimental results (for example on angular distributions) and theoretical considerations might provide a more complete interpretation.

Acknowledgments

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