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Chalcogen atom abstraction from NCE^- (E = O, S, Se) and i-Pr_2S by the excited state of a luminescent tricyano osmium(VI) nitride†

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Upon irradiation by blue LED (λ > 460 nm), the tricyano osmium nitrido complex $[Os^{VI}(N)(L)(CN)_3]^-$ (**OsN**) in its excited state readily abstracts chalcogen atoms from the anions NCE^- (E = O, S, Se) to give the corresponding metal chalcogenonitrosyls $[Os^{II}(N{\equiv}E)(L)(CN)_3]^-$ (**OsNE**) and CN^-. A similar S atom abstraction also occurs in the photoreaction of **OsN** with organic sulfide, such as diisopropyl sulfide, to give **OsNS** and **Os–N=C(CH$_3$)$_2$**. The molecular structures of $(PPh_4)[Os^{II}(N{\equiv}E)(L)(CN)_3]$ have been determined by X-ray crystallography, which show N–O, N–S and N–Se bond distances of 1.206, 1.507 and 1.675 Å, respectively.

Introduction

Metal nitrido complexes (M≡N) have been proposed as key intermediates in N_2 fixation; they are also potentially useful reagents for the nitrogenation of various organic substrates.[1–5] A number of electrophilic nitrido complexes have been reported recently. For instance, *cis*- and *trans*-$[Os^{VI}(N)(tpy)Cl_2]^+$ (tpy = 2,2′:6′,2″-terpyridine) have been shown to exhibit novel electrophilic properties. A variety of reagents such as phosphines, amines, cyanide, azide, arylboranes, amine *N*-oxides, alkenes, and benzenethiols have been reported to react with the osmium nitrido complexes.[6] Higher reactivity is found for Ru≡N and Fe≡N, such as $[Ru(N)(salchda)(MeOH)]^+$ (salchda = *N*,*N*′-bis(salicylidene)-*o*-cyclohexyldiamine dianion)[7] and $[PhB(RIm)_3Fe{\equiv}N]$ (Im = imidazol, R = ^{t}Bu, Mes, and ^{i}Pr$_2$).[8] Although these nitrido complexes exhibit novel electrophilic properties and react readily with a variety of nucleophiles, their reactivity is still relatively limited compared to analogous metal-oxo (M=O) species.[9]

In search of more reactive M≡N species that are comparable to M=O, we recently started to investigate the reactivity of M≡N in their excited states. Accordingly, a highly luminescent Os(VI) nitrido complex, $[Os^{VI}(N)(L)(CN)_3]^-$ (**OsN**, HL = 2-(2-hydroxy-5-nitrophenyl)benzoxazole) with long-lived LMCT excited state has been prepared.[10] This species is highly reactive in the excited state (**OsN***) due to its nitridyl [Os=N$^\bullet$] character. Indeed, upon irradiation with visible light (λ > 460 nm), **OsN*** readily activates the strong C–H bonds of alkanes and arenes,[11] undergoes oxidative *N*-dealkylation of various tertiary amines[12] and C–O bond cleavage of dihydroxybenzene,[13] exhibits formal N atom transfer to aliphatic secondary amines[14] and ring-nitrogenation of aromatic amines.[15] Recently, we have also found that **OsN*** could activate both α- and δ-C–H bonds of alcohols in the presence of PhIO, due to the formation of the highly potent oxidant $PhIO^+$ [16] (Fig. 1).

We report herein that **OsN*** readily undergoes unprecedented chalcogen atom abstraction from the stable inorganic anions NCE^- (N = O, S, Se), as well as from organic sulphide such as i-Pr_2S.

Results and discussion

Upon irradiation of a solution of **OsN** in CH_2Cl_2 containing 10 equiv. of $(PPh_4)NCSe$ with blue LED (λ > 460 nm) for 24 h, the bright yellow solution turned pale-yellow. Electrospray ionization mass spectrometry (ESI/MS, –ve mode) of the resulting solution exhibits a new peak at *m*/*z* 617, which is assigned to $[Os(N{\equiv}Se)(L)(CN)_3]^-$ (**OsNSe**). Similarly, ESI/MS for the photoreaction of **OsN** with 10 equiv. of $(PPh_4)NCS$ for 48 h shows a major peak at *m*/*z* 571, which is assigned to $[Os(N{\equiv}S)(L)(CN)_3]^-$ (**OsNS**) (Fig. 2 and S1†). When the reactions were

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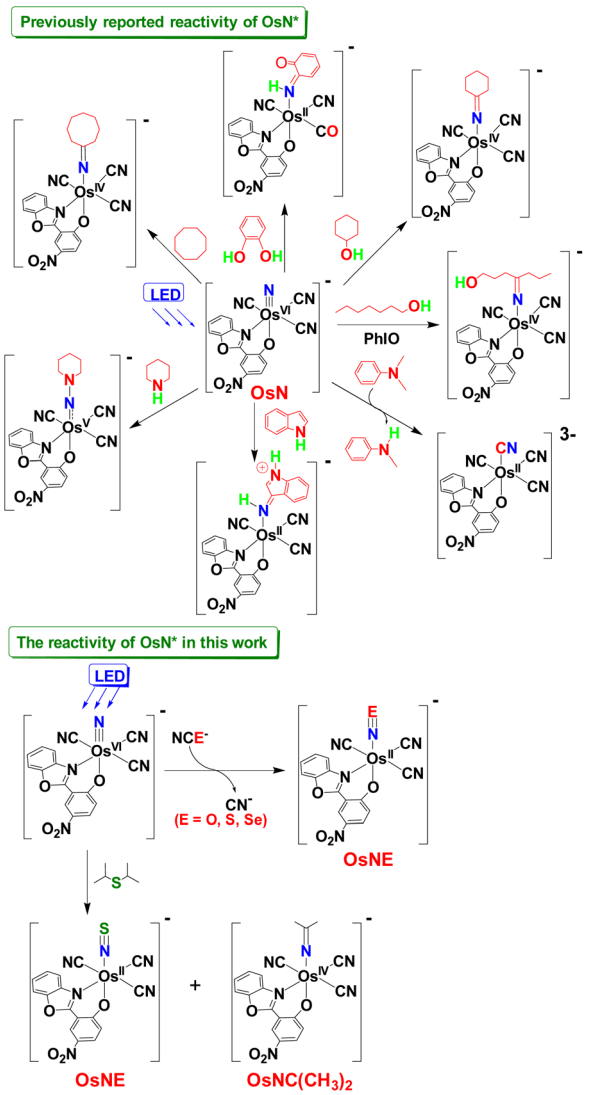

Fig. 1 (a) Reported reactivity of **OsN*** towards various substrates; (b) reaction of **OsN*** with NCE^- and i-Pr_2S in this work.

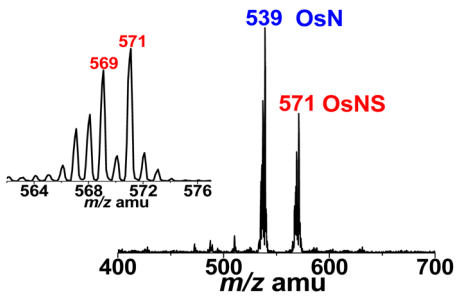

Fig. 2 ESI/MS of the photoreaction of **OsN** with 10 equiv. of $(PPh_4)NCS$ for 24 h showing a new product peak at *m*/*z* 571 (**OsNS**).

carried out on a preparative scale, $(PPh_4)[Os(N{=}E)(L)(CN)_3]$ (**OsNE**, E = Se and S) were isolated as light yellow crystalline solids with 45% and 52% yields, respectively. ESI/MS (−ve mode) of these photoreaction solutions also show a small peak at *m*/*z* = 26 due to the formation of CN^-. **M-NE** complexes have been prepared from the reaction of metal nitrides with S_8 or elemental Se.[17–19] However, to the best of our knowledge, S/Se atom transfer from NCE^- anions, which involves cleavage of strong C=E bonds, has not been reported. The photoreaction of **OsN** with $(PPh_4)NCO$ has also been investigated; however, its reaction rate is much slower, and the yield of $(PPh_4)[Os(N{=}O)(L)(CN)_3]$ (**OsNO**)[20,21] is only ~10%, which is probably due to the stronger C=O bond than C=S and C=Se bonds in NCE^-. O atom transfer to metal nitride usually occurs with oxidants such as Me_3NO.[17a] When ^{15}N-labelled **Os^{15}N** was used, ESI/MS shows that the parent **OsNE** ions all increases by one mass unit, indicating that the N atoms in **OsNE** are from the nitrido ligand rather than from NCE^-.

Both **OsNS** and **OsNSe** are stable for >2 weeks in the solid state or in various solvents at room temperature. However, upon exposure to air for more than two months, these complexes were partially converted into **OsNO** (*m*/*z* 555). Attempts were also made to synthesize the tellurium analog (**OsNTe**) from the photoreaction of **OsN** and $NCTe^-$. However, no products could be isolated, presumably due to the instability of the $[Os(N{=}Te)(L)(CN)_3]^-$ species. Also, no reaction of **OsN*** with elemental tellurium in various solvents was observed, presumably due to the poor solubility of Te.

The IR spectrum of **OsNSe** shows strong ν(C≡N) stretches at 2148, 2133 cm^{-1} and ν(N=Se) stretch at 1136 cm^{-1}. Similar ν(C≡N) stretches in **OsNS** and **OsNO** are also found at 2149, 2133 cm^{-1} and 2150, 2139 cm^{-1}, respectively; while the ν(N=S) and ν(N=O) stretches occur at 1291 cm^{-1} and 1849 cm^{-1}, respectively. The ratio of ν(N=O) to ν(N=S) stretching frequencies in **OsNO** and **OsNS** is 1.432, a typical value for structurally similar NO and NS compounds.[22] The UV/vis spectra of these compounds show strong absorption bands due to ligand centered π–π* transitions below 400 nm, with molar extinction coefficients (ε) on the order of 10^4 M^{-1} cm^{-1} (Fig. 3a). **OsNO** also shows a weak absorption band tailing down to the visible region, while for **OsNS** and **OsNSe** there is a well-defined absorption band in the visible region; these are tentatively assigned to the O^N ligand to metal (Os) charge transfer (LMCT) (Fig. S2 and S3†). All compounds are diamagnetic, as evidenced by their sharp proton signals in the normal range in their ^1H NMR spectra (Fig. S4–S6†).

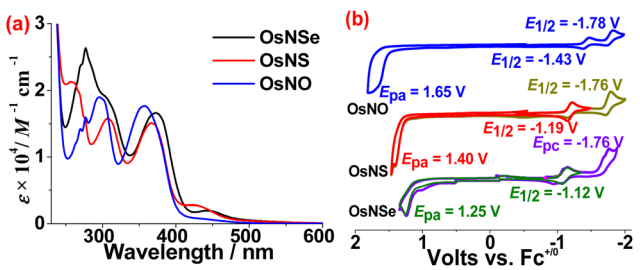

Fig. 3 (a) UV/vis spectra of **OsNE** in CH_3CN; (b) CV of **OsNE** in CH_3CN containing 0.1 M $[^nBu_4N](PF_6)$ with a scan rate of 0.1 V s^{-1}.

Cyclic voltammetry (CV) of **OsNE** was conducted in 0.1 M $[^nBu_4N](PF_6)$ CH_3CN solution. As shown in Fig. 3b, these compounds all show two reduction waves. The first reduction potentials $E_{1/2}$ are in the range of −1.12 to −1.43 V (*vs.* $Fc^{+/0}$), which are dependent on the coordinated NE^+ ligand with the order of NSe (−1.12 V) > NS (−1.19 V) > NO (−1.43 V). Thus, the first reduction waves are tentatively assigned to the ligand-centered $NE^{+/0}$ reduction. On the other hand, the second reduction waves have very similar potentials for these complexes, hence they are assigned to the reduction of the O^N ligand. **OsNE** also exhibits an irreversible wave with E_{pa} of **OsNO** (1.65 V) > **OsNS** (1.40 V) > **OsNSe** (1.25 V), in line with the decreasing π-accepting ability of these chalcogenonitrosyl ligands on going from O to Se. Thus, these oxidation waves should be metal centered, since the Os^{II} center is more stabilized by the stronger π-accepting NO ligand.

Molecular structures

The molecular structures of **OsNE** have been determined by X-ray crystallography and selected bond parameters are listed in Table 1. As shown in Fig. 4, the coordination geometries of the metal centers are similar to that of **OsN**. The Os centers are all 6-coordinated by three CN^- in a meridional configuration, a bidentate O^N ligand and a chalcogenonitrosyl ligand. The Os–N4 bond length in the complexes are similar; 1.727(5) Å in **OsNO**, 1.767(5) Å in **OsNS** and 1.749(3) Å in **OsNSe**, indicating that they have double bond character. These bond lengths follow the order: Os–NO < Os–NSe < Os–NS. This trend is also found in the iridium chalcogenonitrosyl series [Ir(NE){N(CHCHP^{t}Bu$_2$)$_2$}][PF_6].[23] The Os1–N4–E bonds are close to linear; 174.1(4)°, 177.8(4)°, 175.4(2)°, respectively, for E = O, S, Se. The N–E bond lengths are 1.206(6) Å, 1.507(5) Å, and 1.675(3) Å, respectively, for E = O, S, Se, which are very close to the sum of the covalent radii of the double bonds; N–O = 1.17 Å; N–S = 1.54 Å; N–Se = 1.67 Å. The Os–O1$_{(phenoxy)}$ bond lengths are comparable to the value of 2.024(2) Å in (PPh_4)[$Os(NH_3)(L)(CN)_3$],[13] indicating the absence of the strong *trans* influence for these chalcogenonitrosyl ligands.

In our previous work, we showed that **OsN*** readily undergoes an initial one-electron oxidation of various substrates,[12–16] hence it is reasonable to propose that the present photoreactions proceed *via* an initial $1e^-$ transfer (ET) from NCE^- to **OsN*** to generate **Os^{V}N** and the $NCE^•$ radical;

Table 1 Selected bond parameters (Å, °) for **OsNE**

	OsNO	OsNS	OsNSe
Os1–N4	1.727(5)	1.767(5)	1.749(3)
Os1–C2	2.082(7)	2.084(8)	2.069(4)
Os1–C3	2.041(5)	2.037(6)	2.020(4)
Os1–C1	2.091(7)	2.083(8)	2.066(4)
Os1–N5	2.129(4)	2.117(5)	2.127(3)
Os1–O1	2.022(3)	2.034(4)	2.037(2)
N4–E	1.206(6)	1.507(5)	1.675(3)
Os1–N4–E	174.1(4)	177.8(4)	175.4(2)
O1–Os1–N4	174.4(2)	177.1(2)	175.3(1)

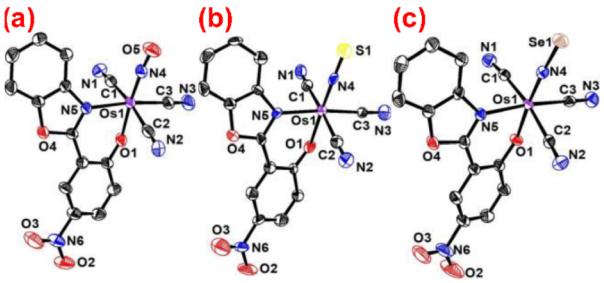

Fig. 4 The structures of the anions **OsNO** (a), **OsNS** (b), and **OsNSe** (c).

this is followed by rapid recombination of the two species to afford the unstable intermediate $[Os^{IV}(L)(CN)_3(N\text{-}ECN)]^{2-}$, which then undergoes spontaneous E–CN bond cleavage to produce **OsNE** and CN^- (Fig. 5). The estimated reduction potentials (E^0) for $NCE^•/NCE^-$ are 1.27 V, 1.63 V, and 2.15 V for E = Se, S, and O, respectively.[24] The observed reaction rates are inversely dependent on the E^o values, consistent with ET being involved in the rate-determining step.

Reaction of OsN* with diisopropyl sulfide

The above results indicate that **OsN*** readily abstracts various chalcogen atoms from NCE^-. A similar reaction occurs between **OsN*** and organic sulphide such as diisopropyl sulfide (i-Pr_2S). Upon irradiation of a solution of **OsN** with 300 equiv. of i-Pr_2S in CH_2Cl_2 for 4 h, ESI/MS shows two new product peaks at *m*/*z* 571 and 581 (Fig. 6), which are assigned to **OsNS** and $[Os^{IV}(L)(CN)_3(N{=}C(CH_3)_2)]^-$ (**Os–N=C(CH$_3$)$_2$**),[12] respectively (Fig. 7). The reaction was also followed by UV/vis spectroscopy, which shows that the absorption band due to **OsN** gradually decreases, while those of the products gradually increase with time (Fig. S7†). When the reaction was carried out on a preparative scale, the two species were isolated with a molar ratio of ~1 : 2.

Oxidative desulfurization is an important process for the removal of sulfur from liquid fuels. In this process, sulfur-containing compounds are converted to their corresponding sulfones/sulfoxides using various oxidants.[25] To the best of our knowledge, direct S atom abstraction from S-containing substrates has yet to be reported. The proposed mechanism for the reaction of **OsN*** with i-Pr_2S is shown in Fig. 8. The first step is ET from i-Pr_2S to **OsN*** to produce **Os^{V}N** and the radical cation i-$Pr_2S^{•+}$, this is followed by their combination to give the Os(IV) species (**I**). **I** then undergoes an internal $2e^-$ transfer to give an Os(II) species (**II**). This is followed by rapid oxidation of

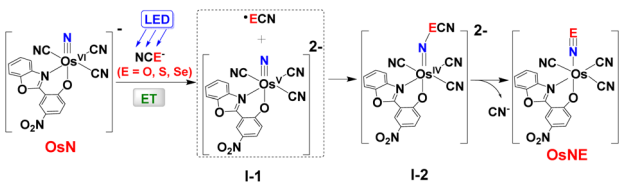

Fig. 5 Proposed mechanism for the reaction of **OsN*** with NCE^-.

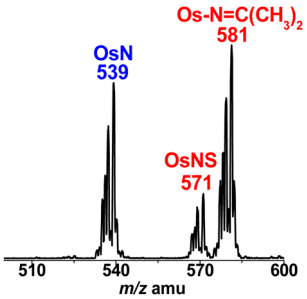

Fig. 6 ESI/MS of the photoreaction of **OsN** with excess i-Pr_2S for 24 h.

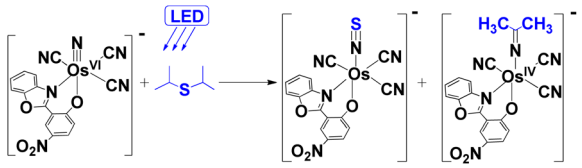

Fig. 7 The photoreaction of **OsN** with i-Pr_2S.

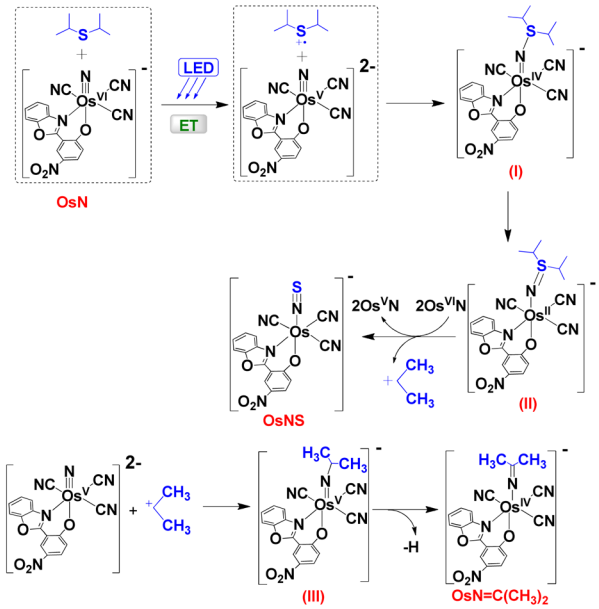

Fig. 8 Proposed mechanism for the reaction of **OsN*** with i-Pr_2S.

II by two 2**OsN***, resulting C–S bond cleavage and the formation of **Os^{V}N**, **OsNS**, and $CH_3CH^+CH_3$. $CH_3CH^+CH_3$ then adds to the nitrido ligand of **Os^{V}N** to form the Os(v) species **III**, which further undergoes an internal $1e^-$ oxidative dehydrogenation to afford **Os–N=C(CH$_3$)$_2$**.[12]

We have carried out DFT calculations on the reaction of **OsN*** + NCS^- and **OsN*** + i-Pr_2S (Fig. S9† and Fig. 9), which support our proposed mechanisms. As shown in Fig. 9, the reaction is downhill in energy after the initial combination of **Os^{V}N** and the radical cation i-$Pr_2S^{\cdot+}$ to give the Os(iv) species. The Os(iv) species then undergoes an internal $2e^-$ transfer to

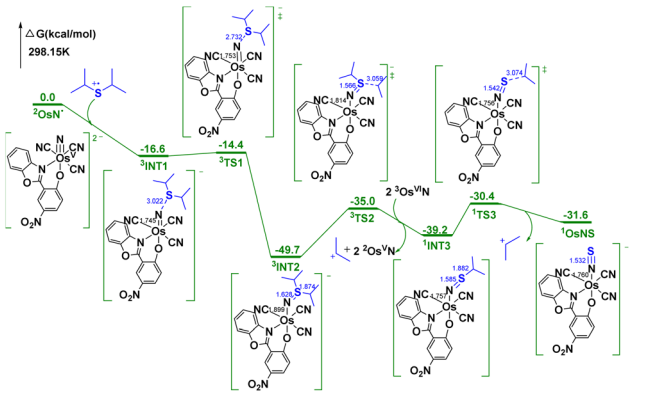

Fig. 9 Gibbs free energy profile for reaction of **OsN*** with i-Pr_2S at the B3LYP-D3(BJ)/def2-TZVPD level.

give an Os(ii) species (^{3}**INT2**) and this is followed by rapid oxidation of ^{3}**INT2** by two **2Os^{VI}N**, resulting in C–S bond cleavage and the formation of **Os^{V}N**, **OsNS**, and $CH_3CH^+CH_3$.

Dechalcogenation of OsNE

Dechalcogenation of **OsNS** and **OsNSe** occur readily by using PPh_3. As shown in Fig. 10a, ESI/MS of **OsNS** with 100 equiv. of PPh_3 for 6 h at 313 K shows a new product peak at *m*/*z* 801, which is tentatively assigned to $[Os^{IV}(L)(CN)_3(N{=}PPh_3)]^-$ (**Os^{IV}N=PPh$_3$**).[26] A minor peak also occurs at *m*/*z* 539, which is due to **OsN**, suggesting that **OsN** may be an intermediate that further reacts with excess PPh_3 to give **Os^{IV}N=PPh$_3$**. The reaction rate of **OsNSe** with PPh_3 is much faster; as shown in Fig. 10b, the ESI/MS for the reaction of **OsNSe** with 5 equiv. of PPh_3 for 0.5 h at 298 K shows two major product peaks at *m*/*z* 539 and 801, while the parent peak at *m*/*z* 617 disappears completely.

The reaction of **OsNE** (E = S, Se) with PPh_3 can be represented by the following equation.

$$[Os^{II}(NE)(L)(CN)_3]^- + PPh_3 = [Os^{VI}(N)(L)(CN)_3]^- + E{=}PPh_3 \quad (1)$$

$$[Os^{VI}(N)(L)(CN)_3]^- + PPh_3 = [Os^{IV}(N{=}PPh_3)(L)(CN)_3]^- \quad (2)$$

When the reactions were carried out on a preparative scale, $SPPh_3$ and $SePPh_3$ were formed and could be extracted with

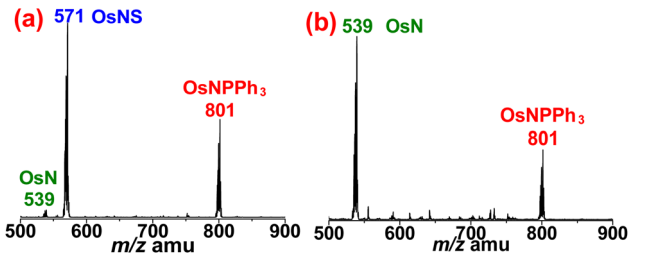

Fig. 10 (a) ESI/MS for **OsNS** with 100 equiv. of PPh_3 in CH_2Cl_2 at 313 K for 6 h; (b) ESI/MS for **OsNSe** with 5 equiv. of PPh_3 in CH_2Cl_2 at 298 K for 0.5 h.

Et_2O with >80% yield (Fig. 11). Although for both **OsNS** and **OsNSe**, the Os(IV) phosphineiminato complex $[Os^{IV}(L)(CN)_3(N{=}PPh_3)]^-$ (**$Os^{IV}N{=}PPh_3$**, *m*/*z* 801) could be observed by ESI/MS, the osmium product that was actually isolated (after chromatography) is the osmium(III) complex $[Os^{III}(L)(CN)_3(NH{=}PPh_3)]^-$ with PPh_4^+ counter ion in ~70% yield (**$Os^{III}NH{=}PPh_3$**). ESI/MS (–ve mode) of **$Os^{III}NH{=}PPh_3$** in MeOH shows a predominant parent anion peak at *m*/*z* 802, which is one mass unit higher than **$Os^{IV}N{=}PPh_3$**. Presumably **$Os^{IV}N{=}PPh_3$** is reduced to **$Os^{III}NH{=}PPh_3$** during the work-up. The IR spectrum of **$Os^{III}NH{=}PPh_3$** shows ν(C≡N) stretches at 2113 and 2084 cm^{-1}, and ν(N–H) stretches at 3276 cm^{-1}. It has a room-temperature magnetic moment of 1.91μ_B (Gouy method, solid sample), consistent with its formulation as a low-spin d^5 Os^{III} compound. The CV of **$Os^{III}NH{=}PPh_3$** in CH_3CN containing 0.1 M $[^nBu_4N](PF_6)$ shows a quasi-reversible Os(III/II) couple at $E_{1/2}$ = –1.27 V (*vs.* $Fc^{+/0}$) (Fig. S8†). There is also a broad wave at ~0.17 V, which is tentatively assigned to **$Os^{IV}N{=}PPh_3$**/**$Os^{III}NH{=}PPh_3$**.

Oxidative dechalcogenation of **OsNSe** and **OsNS** also occurs by using PhIO (Fig. 12), which is much more rapid than with PPh_3. Upon mixing **OsNS** or **OsNSe** with 5 equiv. of PhIO for 0.5 h in CH_3CN, ESI/MS (–ve mode) for both solutions show a predominant peak at *m*/*z* 539. When the reactions were carried out on a preparative scale, **OsN** could be isolated with >90% yield, indicating that **OsNSe** and **OsNS** were almost quantitatively converted to **OsN** by PhIO. Moreover, ESI/MS (–ve mode) for the **OsNS** + PhIO solution also shows a minor peak at *m*/*z* 81, possibly due to HSO_3^-. On the other hand, for the reaction of **OsNSe** with PhIO, a grey precipitate was observed, which is presumably SeO_2. However, no reaction of **OsNO** with PhIO was observed, probably due to its much stronger N–O bond.

Conclusions

We have demonstrated that **OsN*** readily undergoes unprecedented chalcogen atom abstraction from NCE^- and i-Pr_2S; such reaction has not been observed even by metal oxo species. We propose that these reactions occur by initial one-electron oxidation of the substrates by **OsN***. The resulting **OsNE** products readily undergoes dechalcogenation by using PPh_3 or PhIO. Notably PhIO regenerates **OsN** from **OsNE**, which suggests that it is possible to construct a catalytic cycle for dechalcogenation of substrates based on OsN/PhIO/visible light.

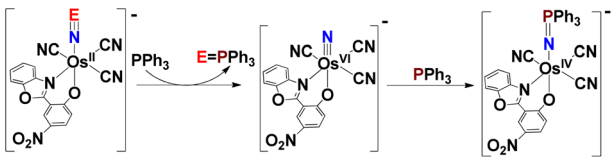

Fig. 11 Chalcogen abstraction by PPh_3 from **OsNE** (E = S, Se).

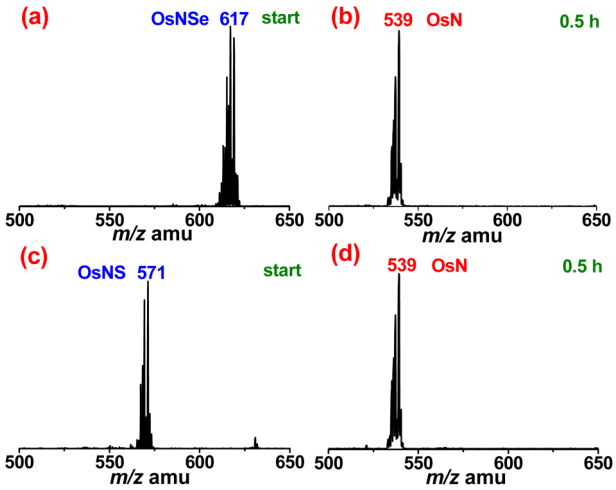

Fig. 12 (a) ESI/MS of **OsNSe** and (b) after addition of 5 equiv. PhIO for 0.5 h in CH_3CN; (c) ESI/MS of **OsNS** and (d) after addition of 5 equiv. PhIO for 0.5 h in CH_3CN.

Experimental

$(PPh_4)[Os(NSe)(L)(CN)_3]$ (OsNSe)

Ten Pyrex tubes (15 × 2 cm) each containing **OsN** (5 mg, 5.7 μmol) and $(PPh_4)NCSe$ (12 mg, 27 μmol) in CH_2Cl_2 were irradiated with blue LED light (λ > 460 nm) for 96 h, whereby the light-yellow solutions became pale yellow. The solvent was removed by a rotary evaporator and the residue was dissolved in a minimum amount of CH_2Cl_2 and then loaded onto a silica gel column. The pale yellow band was eluted by CH_2Cl_2/acetone (v : v, 5 : 1). $(PPh_4)[Os(NSe)(L)(CN)_3]$ was obtained as a yellow microcrystalline solid. Yield: 25 mg, 45%. Light yellow crystals were obtained from the slow diffusion of diethyl ether into a CH_2Cl_2 solution of **OsNSe**. Selected IR (KBr disc, cm^{-1}): ν(C≡N) 2148 and 2133; ν(N≡Se) 1136; ESI/MS (–ve mode): *m*/*z* 617 ($[M]^-$); UV/vis (CH_3CN): λ_{max} [nm] (ε [mol^{-1} dm^3 cm^{-1}]): 256 (21 320), 277sh (15 950), 307 (15 770), 367 (15 080), 427sh (2750). ^1H NMR (400 MHz, $CDCl_3$): δ 8.89 (d, J = 2.9 Hz, 1H, Ar–H), 8.29–8.23 (m, 1H, Ar–H), 7.95–7.89 (m, 5H, Ar–H and PPh_4–H), 7.80 (td, J = 7.8, 3.6 Hz, 8H, PPh_4–H), 7.75–7.71 (m, 1H, Ar–H), 7.70–7.62 (m, 8H, PPh_4–H), 7.53 (dt, J = 10.9, 3.7 Hz, 2H, Ar–H), 6.52 (d, J = 9.3 Hz, 1H, Ar–H). Calcd (%) for $C_{40}H_{27}N_6O_4OsPSe$: C, 50.26; H, 2.85; N, 8.79; found: C, 50.28; H, 2.81; N, 8.76.

$(PPh_4)[Os(NS)(L)(CN)_3]$ (OsNS)

The synthesis of **OsNS** is similar to that of **OsNSe** except $(PPh_4)NCS$ (23 mg, 58 μmol) was used instead. Yield for **OsNS**: 27 mg, 52%. Selected IR Selected IR (KBr disc, cm^{-1}): ν(C≡N) 2149 and 2133; ν(N≡S) 1291; ESI/MS (–ve mode): *m*/*z* 571 ($[M]^-$); UV/vis (CH_3CN): λ_{max} [nm] (ε [mol^{-1} dm^3 cm^{-1}]): 270sh (23 710), 277 (26 320), 302sh (19 240), 374 (16 600), 447 (1940). ^1H NMR (400 MHz, $CDCl_3$): δ 8.90 (d, J = 2.9 Hz, 1H, Ar–H), 8.15–8.11 (m, 1H, Ar–H), 7.95–7.89 (m, 5H, Ar–H and PPh_4–H), 7.80 (td, J = 7.8, 3.6 Hz, 8H, PPh_4–H), 7.75–7.70 (m, 1H, Ar–H),

7.70–7.62 (m, 8H, PPh_4–H), 7.56–7.49 (m, 2H, Ar–H), 6.51 (d, J = 9.3 Hz, 1H, Ar–H). Calcd (%) for $C_{40}H_{27}N_6O_4OsPS$: C, 52.86; H, 2.99; N, 9.25; found: C, 52.82; H, 3.02; N, 9.27.

$(PPh_4)[Os(NO)(L)(CN)_3]$ (OsNO)

The synthesis of **OsNO** is similar to that of **OsNSe** except $(PPh_4)NCO$ (22 mg, 58 μmol) was used instead. Yield for **OsNO**: 5 mg, 10%. The **OsNO** also could be obtained from oxidation of the guanidine precursor (**OsG**) by excess *m*-chloroperbenzoic acid (*m*-cpba) in CH_3CN with about 60% yield.[20,21] Selected IR (KBr disc, cm^{-1}): ν(C≡N) 2150 and 2139; ν(N≡O) 1849; ESI/MS (–ve mode): m/z 555 ($[M]^-$); UV/vis (CH_3CN): λ_{max} [nm] (ε [mol^{-1} dm^3 cm^{-1}]): 270 (14 210), 277 (15 950), 295 (18 980), 357 (17 660), 435sh (760). ^1H NMR (400 MHz, $CDCl_3$): δ 8.92 (s, 1H, Ar–H), 8.03 (d, J = 9.5 Hz, 1H, Ar–H), 7.92 (t, J = 7.4 Hz, 4H, PPh_4–H), 7.80 (d, J = 7.8 Hz, 8H, PPh_4–H), 7.73 (t, J = 7.4 Hz, 2H, Ar–H), 7.65 (dd, J = 12.8, 7.9 Hz, 8H, PPh_4–H), 7.58–7.50 (m, 2H, Ar–H), 6.70 (d, J = 9.3 Hz, 1H, Ar–H). Calcd (%) for $C_{40}H_{27}N_6O_5OsP$: C, 53.81; H, 3.05; N, 9.41; found: C, 53.76; H, 3.02; N, 9.44.

Dechalcogenation of OsNE

$(PPh_4)[Os^{III}(L)(CN)_3(NH{=}PPh_3)]$ (**OsNH═PPh$_3$**). **OsNSe** (20 mg, 20.8 μmol) and PPh_3 (55 mg, 0.2 mmol) were dissolved in CH_2Cl_2 and stirred at room temperature for 6 h to give a dark red solution. The solvent was removed by a rotary evaporator and the residue was dissolved in a minimum amount of CH_2Cl_2 and then loaded onto a silica gel column. The red band was eluted by CH_2Cl_2/MeOH (v : v, 10 : 1). **OsNH═PPh$_3$** was isolated as a red microcrystalline solid. Yield: 16.7 mg, 70%. Selected IR (KBr disc, cm^{-1}): ν(C≡N) 2113 and 2084; ν(N–H) 3276; ESI/MS (–ve mode): m/z 802 ($[M]^-$); μ_{eff} = 1.91μ_B; UV/vis (CH_3CN): λ_{max} [nm] (ε [mol^{-1} dm^3 cm^{-1}]): 263sh (15 180), 268(15 790), 275(15 760), 290sh (14 800), 311(14 790), 392 (12 810), 440sh (10 580), 550sh (970). Calcd (%) for $C_{58}H_{43}N_6O_4OsP_2$: C, 61.10; H, 3.80; N, 7.37; found: C, 61.13; H, 3.78; N, 7.39.

Author contributions

The manuscript was written through the contributions of all authors. All authors have given approval to the final version of the manuscript.

Conflicts of interest

There are no conflicts to declare.

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