mercury in the periodic table portends activity as an electrophile toward aromatics.[12] Conclusions regarding the structural basis of chelatoselective fluorescence perturbation suggest variations on the incorporation of such "nonclassical" selectivity into future fluoroionophores.

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(12) The observation of aqueous electrophilic cadmiation raises interesting possibilities for the undetermined mechanism of cadmium toxicity.

Rhenium Oxo–Methylidene and Oxo–Methylidyne Compounds and Evidence for Facile Methylidene Proton Exchange

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Rhenium oxo–alkylidene species, in some form, are probably the active catalysts in several olefin metathesis catalyst systems,[1-4] but to our knowledge there is only one example of a well-characterized rhenium oxo–alkylidene complex.[5] We report here the synthesis of two new dinuclear rhenium oxo–methylidene compounds, and for one of these we demonstrate facile methylidene proton exchange. Such a process may be relevant to deactivation of oxo-based metathesis catalysts. Additionally, we report the preparation of an unusual anionic rhenium oxo–methylidyne complex.

The d^2 oxo–methyl complex ReOMe$_3$(PMe$_3$),[6] prepared in situ from ReOMe$_2$Cl(PMe$_3$)$_2$ and 0.5 equiv of ZnMe$_2$, decomposed rapidly in pentane at room temperature (6 h) to give methane and the oxo–methylidene compound Re$_2$(μ-CH$_2$)(μ-O)(O)Me$_4$(PMe$_3$)$_2$ (**1**; Figure 1).[7] Compound **1** was isolated as a blue crystalline solid from pentane at −20 °C in 77% yield. By ^{1}H NMR the decomposition was nearly quantitative, and 1 equiv of methane was produced for every molecule of **1**.

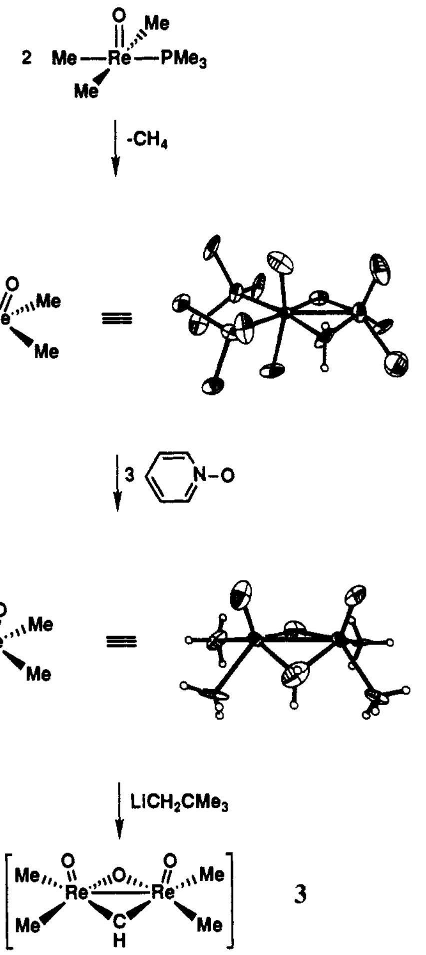

Figure 1. Reaction scheme described in the text. ORTEP plots (50% probability levels) of Re$_2$(μ-CH$_2$)(μ-O)(O)Me$_4$(PMe$_3$)$_2$ (**1**) and Re$_2$(μ-CH$_2$)(μ-O)O$_2$Me$_4$ (**2**) are presented at the right of their respective stick drawings.

An X-ray crystallographic study (ORTEP, Figure 1)[8,9] revealed that **1** has square-pyramidal and octahedral rhenium centers. The Re–Re distance of 2.548 (2) Å is consistent with a single bond.[2a,10] Extended Hückel calculations[11] indicate that **1** has a covalent

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(7) Amounts used in a typical preparation: ReOMe$_2$Cl(PMe$_3$)$_2$ (1.00 g, 2.39 mmol); ZnMe$_2$ (0.144 mL, 1.19 mmol); pentane (50 mL).

(8) Anal. Calcd for Re$_2$P$_2$O$_2$C$_{11}$H$_{32}$: C, 20.92; H, 5.11. Found: C, 20.49; H, 4.77. ^{1}H NMR (C$_6$D$_6$): δ 10.34 (ddd, 1, J_{HH} = 6.9 Hz, J_{PH} = 4.2 Hz, J_{PH} = 2.2 Hz, μ-CH_aH$_b$ cis with respect to Re$\equiv$O), 8.31 (dd, 1, J_{HH} = 6.9 Hz, J_{PH} = 3.2 Hz, μ-CH$_a$$H_b$ trans with respect to Re$\equiv$O). ^{13}C NMR (C$_6$D$_6$): δ 138.3 (dddd, 1, J_{CP}(trans) = 34 Hz, J_{CP}(cis) = 12 Hz, J_{CH} = 134 Hz, J_{CH} = 146 Hz, μ-CH$_2$). IR (Nujol, CsI, cm^{-1}): ν(Re$\equiv$O) 988 s (ν(Re$\equiv$^{18}O) 938). Crystal data for Re$_2$P$_2$O$_2$C$_{11}$H$_{32}$ at −88 (1) °C: blue blocks, 0.20 × 0.25 × 0.30 mm, monoclinic, space group *Cc*, a = 15.386 (5) Å, b = 10.295 (4) Å, c = 23.753 (9) Å, β = 92.86 (3)°, d_{calcd} = 2.23 g cm^{-3}, Z = 8, μ = 132.1 cm^{-1}. X-ray diffraction data were collected on a Nicolet R3m/V diffractometer using graphite-monochromated Mo Kα radiation (λ = 0.71073 Å) in the θ–2θ scan mode. A linear decay correction based on the intensity changes of the check reflections (to correct for an ca. 9% average decrease in intensity after 120 h of exposure), a semiempirical absorption correction (XEMP), and Lorentz and polarization corrections were applied to the data. The absolute configuration was confirmed by inversion of configuration and by refinement of the η parameter (η = 0.98 (5)). A total of 10820 reflections were collected in the range 4° < 2θ < 48° ($\pm h,k,\pm l$); 5911 were unique reflections (R_{int} = 0.0518), and 4741 with $F_o > 6\sigma(F_o)$ were used in the structure solution. $R(F)$ = 0.0437; $R_w(F)$ = 0.0444. Structure factors from the following: *International Tables for X-ray Crystallography*; Kynoch: Birmingham, England, 1974; Vol. IV.

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Re–Re σ bond and two electrons in a nonbonded orbital concentrated on the octahedral Re center; thus, the molecule is best described as a mixed-valent "d^3–d^1 complex".

The lone pair of electrons on the octahedral center suggested that oxidation of **1** was feasible. Addition of 3 equiv of pyridine *N*-oxide to a blue toluene solution of **1** resulted in a slow color change of the solution to orange and the precipitation of a white solid (Me_3PO). The orange solution was filtered through an alumina pad (grade V) to remove Me_3PO, and subsequent crystallization from toluene at −80 °C gave orange plates of diamagnetic d^1–d^1 $Re_2(\mu\text{-}CH_2)(\mu\text{-}O)O_2Me_4$ (**2**) in 75% yield.[12]

The structure of **2** (ORTEP, Figure 1)[9,13] resembles those of the d^1–d^1 dimers $[Re(\mu\text{-}O)(O)R_2]_2$ (R = Me, CH_2CMe_3, or CH_2CMe_2Ph),[2a,10] for which each Re center has a square-pyramidal geometry with a terminal oxo ligand in the apical position. The Re–Re distance (2.654 (2) Å) is consistent with a single bond (cf. Re–Re = 2.593 (1) Å in $[Re(\mu\text{-}O)(O)Me_2]_2$).[2a]

The reaction of **2** in benzene-d_6 with methanol-d_4 (100 equiv) resulted in deuterium incorporation into both methylidene proton sites (eq 1). The rates of deuterium incorporation were markedly different for the two inequivalent sites, with the incorporation much more rapid (minutes vs days) at the proton position trans with respect to the terminal oxo ligands (H^t) than at the cis position (H^c). The addition of 100 equiv of glacial acetic acid-d_4 to **2** in benzene-d_6, followed immediately by 100 equiv of methanol-d_4, resulted in a relatively much slower deuterium enrichment at both sites, indicating that acid inhibits the deuterium exchange reaction.

$$\mathbf{2} \xrightarrow[\text{minutes}]{C_6D_6/CD_3OD} Re_2(\mu\text{-}CH^cD^t)(\mu\text{-}O)O_2Me_4 \xrightarrow[\text{1-2 days}]{C_6D_6/CD_3OD} \underset{\mathbf{2}\text{-}d_2}{Re_2(\mu\text{-}CD^cD^t)(\mu\text{-}O)O_2Me_4} \quad (1)$$

In related experiments, an approximately 1:1 mixture of $Re_2(\mu\text{-}CD_2)(\mu\text{-}O)O_2Me_4$ (**2**-d_2) and **2** in benzene-d_6 within minutes of preparation gave an ≈1:1:1:1 mixture of **2**, **2**-d_2, $Re_2(\mu\text{-}CH^cD^t)(\mu\text{-}O)O_2Me_4$, and $Re_2(\mu\text{-}CD^cH^t)(\mu\text{-}O)O_2Me_4$. The crossover was slowed by the addition of acetic acid-d_4. Additionally, $Re_2(\mu\text{-}CH^cD^t)(\mu\text{-}O)O_2Me_4$ alone in benzene-d_6 gave the four possible H/D products (≈1:1:1:1 ratio) on standing for 4 days (eq 2). It is not clear in this experiment, nor in the reactions involving methanol as a deuterium source, whether the deuterium incorporation into the H^c position is via inter or intramolecular processes.

$$Re_2(\mu\text{-}CH^cD^t)(\mu\text{-}O)O_2Me_4 \xrightarrow[C_6D_6]{\text{4 days}} Re_2(\mu\text{-}CH^cD^t)(\mu\text{-}O)O_2Me_4 + Re_2(\mu\text{-}CD^cH^t)(\mu\text{-}O)O_2Me_4 + \mathbf{2} + \mathbf{2}\text{-}d_2 \quad (2)$$

These facile deuterium crossover and exchange reactions suggested that deprotonation of **2** was feasible. Thus, the reaction of **2** with 1 equiv of $LiCH_2CMe_3$ in pentane gave neopentane and $Li[Re_2(\mu\text{-}CH)(\mu\text{-}O)O_2Me_4]$ (**3**; Figure 1) as a hydrocarbon-insoluble orange powder in 85% yield.[14] The reaction of $Re_2(\mu\text{-}CH^cD^t)(\mu\text{-}O)O_2Me_4$ with 1 equiv of $LiCH_2CMe_3$ gave only protio **3** by NMR integration (i.e., no $Li[Re_2(\mu\text{-}CD)(\mu\text{-}O)O_2Me_4]$).

A mechanism involving virtual dissociation of **2** to **3** and H^+, perhaps with another molecule of **2** acting as the base in the crossover experiments, would account for the fast deuterium incorporation and crossover observed at the methylidene H^t position, and the acid inhibition. The basic site in **2** would likely be the bridging oxo group (cf. $[Re(\mu\text{-}O)OCp^*]_2 + 2H^+ \rightarrow \{[Re(\mu\text{-}OH)OCp^*]_2\}^{2+}$).[15]

One component of an alternative mechanism is illustrated in eq 3. In this case, the fast H^t/D incorporation and crossover would

$$Re_2(\mu\text{-}CH^cH^t)(\mu\text{-}O)O_2Me_4 \rightleftarrows Re_2(\mu\text{-}CH^c)(\mu\text{-}OH^t)O_2Me_4 \quad (3)$$

occur via a bridging hydroxide, which results from a 1,3-shift of the H^t methylidene proton to the bridging oxo ligand in **2**, and charged species would not necessarily be involved. Acid would inhibit the equilibrium by binding to the bridging oxo group in **2**. In eq 3 the proton transfer would result in the formation of partial Re–(μ-CH) multiple bonds without significant loss of Re–(μ-O) multiple bonding, providing a driving force for the transfer.[4a,16]

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Supplementary Material Available: Procedures for the X-ray structure determinations, complete tables of bond distances and angles, atomic coordinates, non-hydrogen atom anisotropic displacement parameters, packing diagrams, and ORTEP plots showing the atom-numbering schemes for **1** and **2** (25 pages); listing of observed and calculated structure factors for **1** and **2** (28 pages). Ordering information is given on any current masthead page.

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[12] Amounts used in a typical preparation: pyridine *N*-oxide (0.070 g, 0.074 mmol); **1** (0.155 g, 0.240 mmol); toluene (30 mL).

[13] Anal. Calcd for $Re_2O_3C_5H_{14}$: C, 12.14; H, 2.85. Found: C, 12.42; H, 2.77. By ^{1}H NMR, **2** has C_s symmetry in solution. ^{1}H NMR (C_6D_6): δ 9.49 (d, 1, J_{HH} = 14.5 Hz, $\mu\text{-}CH_a\mathit{H}_b$ trans with respect to $Re{\equiv}O$), 6.01 (d, 1, J_{HH} = 14.5 Hz, $\mu\text{-}C\mathit{H}_aH_b$ cis with respect to $Re{\equiv}O$). ^{13}C NMR (C_6D_6): δ 158.1 (dd, 1, J_{CH_a} = 161 Hz, J_{CH_b} = 131 Hz, $\mu\text{-}\mathit{C}H_2$). IR (Nujol, CsI, cm^{-1}): $\nu(Re{\equiv}O)$ 1014 s, 1001 m, ν(asym ReORe) 748 w ($\nu(Re_2{}^{18}O_3)$ 973, 960, 720). Crystal data for $C_5H_{14}O_3Re_2$ at −76 (1) °C: orange plates, 0.20 × 0.20 × 0.10 mm, triclinic, space group $P\bar{1}$, a = 5.853 (3) Å, b = 5.912 (2) Å, c = 15.895 (7) Å, α = 89.72 (4)°, β = 85.34 (5)°, γ = 60.52 (3)°, d_{calcd} = 3.44 g cm^{-3}, Z = 2, μ = 256.7 cm^{-1}. X-ray diffraction data were collected on a Nicolet R3m/V diffractometer using graphite-monochromated Mo Kα radiation (λ = 0.71073 Å) in the θ–2θ scan mode. A semiempirical absorption correction (XEMP) and Lorentz and polarization corrections were applied to the data. A total of 2339 reflections were collected in the range $4° < 2\theta < 50°$ ($h,\pm k,\pm l$); 1646 were unique reflections (R_{int} = 0.056), and 1383 with $F_o > 6\sigma(F_o)$ were used in the structure solution. $R(F)$ = 0.0450; $R_w(F)$ = 0.0475.

[14] Amounts used in a typical preparation: $LiCH_2CMe_3$ (0.006 g, 0.08 mmol); **2** (0.038 g, 0.08 mmol); pentane (20 mL). ^{1}H NMR (CD_3CN): δ 12.23 (s, 1, $\mu\text{-}C\mathit{H}$), 2.10 (s, 6, $C\mathit{H}_3$), 1.35 (s, 6, $C\mathit{H}_3$). ^{13}C NMR (CD_3CN): δ 258.4 (d, 1, J_{CH} = 183 Hz, $\mu\text{-}\mathit{C}H$), 25.7 (q, 2, J_{CH} = 125 Hz, $\mathit{C}H_3$), 19.0 (q, 2, J_{CH} = 128 Hz, $\mathit{C}H_3$). IR (Nujol, CsI, cm^{-1}): $\nu(Re{\equiv}O)$ 981 s, 967 m, ν(asym ReORe) 668 w.

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Hydration of Cavities in Proteins: A Molecular Dynamics Approach

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Internal water molecules play an important role in the structure and function of proteins.[1-5] The ability to predict their structural and thermodynamic properties would be of value in, e.g., the design of ligands, such as drugs; the study of protein–protein interfaces and protein folding; and the location of water molecules in protein structures solved at low resolution by X-ray crystallography.

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