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Journal of Organometallic Chemistry 673 (2003) 67–76
Journal of Organometallic Chemistry
www.elsevier.com/locate/jorganchem

Preparation of substituted transition-metal (η^1-propargyl complexes and their [3+2] cycloaddition reactions with sulfur dioxide and disulfur monoxide. Transition-metal–carbon bond cleaving reactions of the cycloadducts which yield oxathiolene oxides and dithiolene oxides

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Received 14 January 2003; received in revised form 13 March 2003; accepted 14 March 2003

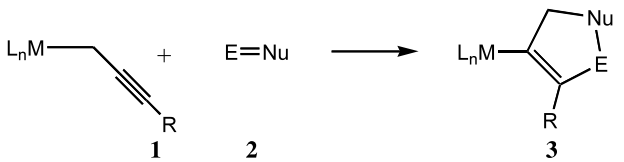
Abstract

The preparations of several new cyclopentadienyl iron dicarbonyl η^1-2-alkynyl complexes are reported. Their [3+2] cycloaddition reactions with sulfur dioxide and disulfur monoxide yielded transition-metal substituted 1,2-oxathiolene-2-oxides and 1,2-dithiolene-1-oxides, respectively. The transition-metal was cleaved from the oxathiolene-oxide and dithiolene-oxide containing complexes to produce new sulfur heterocycles.

Keywords: Propargyl complexes; Alkynyl complexes; [3+2] Cycloaddition; Sulfur heterocycles

1. Introduction

Cycloaddition reactions between transition-metal η^1-2-alkynyl (**1**) and η^1-allyl complexes (**1**) and unsaturated electrophilic reagents (**2**) were first reported about 30 years ago [1]. These [3+2] cycloaddition reactions have been shown to yield transition-metal substituted five-membered-ring heterocycles and carbacycles (**3**) [1].



1 **2** **3**

Over the last 15 years we have also reported a number of examples of these types of cycloaddition reactions [2]. We have been particularly interested in developing this chemistry as a new synthetic method for the preparation of unusual sulfur heterocycles. We are interested in five-membered-ring sulfur heterocycles as synthetic targets because of (1) their cancer chemopreventive effects since they function as anticarcinogenic enzyme inducers [3] and (2) a recent report that 1,2-dithiolanes and 1,2-dithianes look particularly promising as inhibitors of HIV type 1 replication [4].

We recently reported some oxathiolene-oxides and dithiolene-oxides which function as inducers of ferritin expression, glutathione *S*-transferases, and NAD(P)H quinone oxidoreducatase [5]. In continuation of our efforts in this area, we report here the preparation of cyclopentadienyl iron dicarbonyl-η^1-alkynyl complexes which were targeted for preparation based on their potential to lead to new anticarcinogenic enzyme inducers. Subsequent [3+2] cycloaddition reactions of these complexes with sulfur dioxide and disulfur monoxide are reported along with demetallation reactions of these metal substituted cycloadducts. The biological activities of these compounds will be reported elsewhere.

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doi:10.1016/S0022-328X(03)00167-0

2. Experimental

2.1. General

All proton nuclear magnetic resonance (NMR) spectra were obtained using a Bruker 300 MHz spectrometer operating at 300.1 MHz and referenced to the residual proton signal of a deuterated solvent. All ^{13}C-NMR spectra were obtained using a Bruker 300 MHz spectrometer operating at 75.48 MHz, or a Bruker 500 MHz spectrometer operating at 125.8 MHz. Spectra were referenced to the residual carbon signal of a deuterated solvent. Infrared (IR) spectra were obtained on either a Perkin–Elmer 1620 FTIR or a Mattson Genesis II FTIR. Melting points were obtained on a Mel-Temp apparatus and are reported uncorrected. All elemental analyses were performed by Atlantic Microlab, Inc., of Norcross, Georgia. All high-resolution mass spectral analyses were performed by Duke Mass Spectrometry Facility, Duke University. Diethyl ether and tetrahydrofuran were distilled from sodium/benzophenone under nitrogen immediately prior to use. Dichloromethane was distilled from calcium hydride immediately before use. All reactions were carried out under an atmosphere of dry nitrogen gas unless otherwise noted. Cyclopentadienyliron dicarbonyl dimer, mercury, and dichlorobis(triphenylphosphine) palladium (II) were purchased from Strem Chemicals. Ammonium cerium (IV) nitrate, 4′-iodoacetophenone, 4-iodobenzotrifluoride, triethylamine, *p*-toluene sulfonyl chloride, sulfur dioxide (g), and pyridine were purchased from Aldrich. Sulfur dioxide (1 M) in chloroform was purchased from Alfa Aesar. Propargyl alcohol was purchased from Farchan Laboratories. Deuterated solvents were purchased from Cambridge Isotope Laboratories. All reagents were used as received. 4,5-Diphenyl-3,6-dihydro-1,2-dithiin-1-oxide (**26**) was prepared using an adaptation of our previously reported procedure [6].

2.2. 2-Chloro-1-ethynyl-cyclohexanol (*5*)

A flame-dried two-neck flask cooled under N_2, containing 0.5 M ethynylmagnesium bromide in THF (450 ml, 225.0 mmol) was cooled to 0 °C. 2-Chlorocyclohexanone (**4**) (25.0 g, 189.0 mmol) was added slowly over several minutes. The solution was stirred at 0 °C for 15 min and then stirred for 1 h at room temperature, then poured into cold NH_4Cl (200 ml). After vigorous shaking and separation of the layers, extraction with diethyl ether (3 × 50 ml) was used to obtain the product. The solvent was removed by rotary evaporation at 25 °C. The crude product was distilled through a short Vigreux column at 10 mmHg. The desired product (**5**) (19.062 g, 120.0 mmol, 63%) came off in the temperature range of 82–84 °C as a 1:1 mixture of diastereomers. No attempt was made to separate the diastereomers since the chiral centers were subsequently removed by dehydration. ^{1}H-NMR ($CDCl_3$) 4.30 (dd, $J = 10$, 3 Hz, α-Cl H in 1 diastereomer), 3.70 (dd, $J = 6$, 4 Hz, α-Cl H in 1 diastereomer), 2.85 (br s, 1H, OH), 2.45 (s, 1H), 2.05 (m, 1H), 1.92 (m, 1H), 1.80 (m, 2H), 1.6 (m, 2H), 1.45 (m, 2H). EIMS (*m*/*z*) [M^+] 158 (6), 123 (16), 105 (13), 95 (31), 81 (100), 68 (47), 53 (47).

2.3. 1-Chloro-2-ethynylcyclohexene (*6*)

In a flame-dried flask cooled under N_2, 2-chloro-1-ethynylcyclohexanol (**5**) (19.062 g, 120.0 mmol) was added to pyridine (100 ml) and cooled to 0 °C. $POCl_3$ (20.236 g, 132.0 mmol) was added over 30 min. The reaction mixture was stirred at room temperature for 15 h, then heated to 70 °C for 1 h. After cooling, ice (200 g) was added, the layers were separated and the aqueous layer was extracted with diethyl ether (3 × 50 ml). The combined extracts were washed with 10% HCl, water and saturated $NaHCO_3$. The product was dried with magnesium sulfate and excess solvent was removed by rotary evaporation. Another wash with 1.2 M HCl (2 × 50 ml) was carried out to remove residual pyridine from the product (**6**) (8.552 g, 60.9 mmol, 51%). ^{1}H-NMR ($CDCl_3$) 3.2 (s, 1H), 2.35 (m, 2H), 2.22 (m, 2H), 1.65 (m, 2H), 1.55 (m, 2H). ^{13}C-NMR ($CDCl_3$) 138.7, 117.3, 82.2, 82.1, 34.0, 31.1, 23.8, 22.2. Anal. Calc. for C_8H_9Cl: C, 68.34; H, 6.45%. Found: C, 68.51; H, 6.54%.

2.4. 3-(2′-Chloro-2′-cyclohexenyl)-2-propyn-1-ol (*7*)

1-Chloro-2-ethynylcyclohexene (**6**) (7.606 g, 54.1 mmol) was dissolved in anhydrous diethyl ether (175 ml), cooled to −78 °C, and treated with 2.5 M *n*-Butyllithium (23.8 ml, 59.5 mmol) in hexane. The mixture was stirred for 90 min and then paraformaldehyde (3.25 g, 36.1 mmol) was added. The mixture was then allowed to warm to room temperature overnight, poured into NH_4Cl (100 ml) and extracted with diethyl ether (3 × 50 ml). The organic extracts were dried with magnesium sulfate, rotary evaporation was used to remove the solvent, and the product was vacuum dried. The product (**7**) (5.717 g, 33.5 mol, 62%) was obtained by vacuum distillation at 110–115 °C (1 mmHg). ^{1}H-NMR ($CDCl_3$) 4.20 (s, 2H), 2.20 (t, $J = 6.5$ Hz, 2H), 2.08 (t, $J = 6.5$ Hz, 2H), 1.98 (s, 1H), 1.5 (m, 2H), 1.4 (m, 2H). ^{13}C-NMR ($CDCl_3$) 137.7, 117.6, 92.1, 84.3, 52.0, 34.0, 31.2, 23.7, 22.1. EI HRMS (*m*/*z*) Calc. for [M^+] ($C_9H_{11}ClO$): 170.0498. Found: 170.0495.

2.5. 1-Tosyl-3-(2′-Chloro-2′-cyclohexenyl)-2-propyne (*8*)

3-(2′-Chloro-2′-cyclohexenyl)-2-propyn-1-ol (**7**) (4.21 g, 25.0 mmol) was dissolved in anhydrous diethyl ether (100 ml) and *p*-toluene sulfonyl chloride (4.525 g, 23.7

mmol) was added. The solution was cooled to −15 °C and powdered KOH (7.0125 g, 125.0 mmol) was added one equivalent at a time over 30–45 min. The mixture was then stirred at −15 °C for 90 min. Ice water (100 ml) was then added and the product was extracted with diethyl ether (2 × 50 ml). The extracts were dried with magnesium sulfate and the solvent was removed by rotary evaporation. The product (**8**) (7.02 g, 21.6 mmol, 86%) was then dried under high vacuum. ^{1}H-NMR ($CDCl_3$) 7.74 (d, $J = 6.5$ Hz, 2H), 7.28 (d, $J = 6.5$ Hz, 2H), 4.85 (s, 2H), 2.39 (s, 3H), 2.20 (m, 2H), 2.00 (m, 2H), 1.6 (m, 2H), 1.5 (m, 2H). ^{13}C-NMR ($CDCl_3$) 145.3, 139.3, 133.7, 130.2, 128.5, 116.9, 87.5, 85.2, 59.0, 34.0, 30.8, 23.5, 22.0, 21.9. Anal. Calc. for $C_{16}H_{17}SOCl$: C, 59.16; H, 5.28%. Found: C, 59.31; H, 5.17%.

2.6. General procedure for synthesis of substituted phenyl propargyl alcohols

Following a literature procedure, [2d] the appropriate iodobenzene was dissolved in 10–30 ml of triethylamine, and propargyl alcohol was added. The reaction mixture was degassed using nitrogen. $Pd(PPh_3)_2Cl_2$ (0.01 mol%) and CuI (0.02 mol%) were added to the solution, and the solution was again degassed with nitrogen. The reaction was stirred at room temperature for 2 h. Water (20 ml) was then added, and the reaction mixture was extracted with ethyl acetate (3 × 20 ml). The organic layers were combined and dried over $MgSO_4$ and filtered. The solvent was removed under reduced pressure.

2.6.1. 3-(4′acetylphenyl)-2-propyn-1-ol (*12*)

4′-Iodoacetophenone (**9**) (3.00 g, 12.20 mmol), propargyl alcohol (**11**) (0.72 ml, 12.4 mmol), $Pd(PPh_3)_2Cl_2$ (0.089 g, 0.127 mmol), and CuI (0.048 g, 0.25 mmol) were reacted using the above procedure. The crude product was purified using recrystallization in pentane. The resulting product (**12**) was an orange solid (1.707 g, 9.81 mmol, 80%), m.p. 73–76 °C. IR (NaCl) 3381, 2910, 1661 cm^{-1}. ^{1}H-NMR ($CDCl_3$): 7.89 (d, $J = 6.7$ Hz, 2H), 7.50 (d, $J = 6.8$ Hz, 2H), 4.51 (s, 2H), 2.58 (s, 3H), 1.61 (s, 1H). ^{13}C-NMR ($CDCl_3$) 197.62, 136.90, 132.17, 128.60, 127.82, 90.91, 85.27, 51.98, 26.96. EI HRMS (m/z) Calc. for [M^+] ($C_{11}H_{10}O_2$): 174.0681. Found: 174.0678.

2.6.2. 3-(4′-Trifluoromethylphenyl)-2-propyn-1-ol (*13*)

4-Iodobenzotrifluoride (**10**) (0.908 g, 3.34 mmol), propargyl alcohol (**11**) (0.21 ml, 3.6 mmol), $Pd(PPh_3)_2Cl_2$ (0.027 g, 0.038 mmol), and CuI (0.010 g, 0.052 mmol) were reacted using the above procedure. The crude product was purified using pentane to precipitate the by-product. The pentane was removed from the remaining orange solution using rotary evaporation. The resulting product (**13**) was a waxy orange solid (0.307 g, 1.63 mmol, 49%), m.p. 35–37 °C. IR (KBr) 3609, 2927, 2872, 1616 cm^{-1}. ^{1}H-NMR ($CDCl_3$): 7.53 (d, $J = 8.8$ Hz, 2H), 7.49 (d, $J = 8.8$ Hz, 2H), 4.51 (s, 2H), 2.83 (s, 1H). ^{13}C-NMR ($CDCl_3$) 132.25 (s), 130.69 (q, $J = 32.7$ Hz), 126.79 (q, $J = 1.1$ Hz), 125.59 (q, $J = 3.8$ Hz), 124.22 (q, $J = 272.2$ Hz), 90.17 (s), 84.56 (s), 51.67 (s). Anal. Calc. for $C_9H_7F_3O$: C, 60.01; H, 3.53%. Found: C, 59.71; H, 3.73%.

2.7. General procedure for synthesis of alkynyl tosylates

In an adaptation of a literature procedure, [2d] the corresponding propargyl alcohol was dissolved in diethyl ether (50 ml) and *p*–toluene sulfonyl chloride (one equivalent) was added. The solution was cooled to 0 °C and freshly powdered potassium hydroxide (57.0 equivalents) was added five equivalents at a time over a 30 min period. The reaction mixture was allowed to stir at 0 °C for 2 h. Ice water (50 ml) was then added, and the mixture was extracted with diethyl ether (3 × 25 ml). The solution was dried over $MgSO_4$, and the solvent was removed under reduced pressure. The product was triturated with distilled pentane, cooled to −15 °C, and the solvent decanted. The remaining product was dried under vacuum.

2.7.1. 1-Tosyl-3-(4′-acetylphenyl)-2-propyne (*14*)

3-(4′-Acetylphenyl)-2-propyn-1-ol (**12**) (1.48 g, 8.50 mmol), *p*-toluene sulfonyl chloride (1.62 g, 8.50 mmol), and potassium hydroxide (19.4 g, 485 mmol) were reacted using the above procedure to yield the product (**14**) (2.03 g, 6.20 mmol, 76%) as a tan solid. M.p. 69–73 °C. IR (KBr) 2990, 1685, 1178 cm^{-1}. ^{1}H-NMR ($CDCl_3$) 7.80 (m, 4H), 7.27 (m, 4H), 4.89 (s, 2H), 2.53 (s, 3H), 2.34 (s, 3H). ^{13}C-NMR ($CDCl_3$) 197.49, 145.53, 137.35, 133.71, 132.27, 130.23, 128.60, 128.49, 126.56, 88.29, 84.11, 58.58, 26.97, 22.00. Anal. Calc. for $C_{18}H_{16}O_4S$: C, 65.84; H, 4.91%. Found: C, 66.47; H, 4.97%.

2.7.2. 1-Tosyl-3-(4′-trifluoromethylphenyl-2-propyne (*15*)

3-(4′-Trifluoromethylphenyl)-2-propyn-1-ol (**13**) (0.31 g, 1.5 mmol), *p*-toluene sulfonyl chloride (0.29 g, 1.5 mmol), and potassium hydroxide (3.54 g, 88.5 mmol) were reacted using the above procedure to yield the product (**15**) (0.44 g, 1.2 mmol, 82%) as an orange solid. M.p. 67–70 °C. IR (KBr) 3056, 1617, 1176 cm^{-1}. ^{1}H-NMR ($CDCl_3$) 7.85 (d, $J = 8.4$ Hz, 2H), 7.54 (d, $J = 8.1$ Hz, 2H), 7.35 (m, 4H), 4.95 (s, 2H), 2.40 (s, 3H). ^{13}C-NMR ($CDCl_3$) 145.57, 133.70, 132.40, 131.20 (q, $J =$ 32.81 Hz), 130.24, 128.58, 127.41, 125.58 (q, $J = 11.28$ Hz), 124.09 (q, $J = 272.35$), 87.72, 83.46, 58.52, 21.93. Anal. Calc. for $C_{17}H_{13}F_3O_3S$: C, 57.62; H, 3.70%. Found: C, 57.66; H, 3.70%.

2.8. General procedure for synthesis of iron alkynyl complexes

Following a literature procedure, [2d] the iron anion was generated by stirring a THF solution of $[CpFe(CO)_2]_2$ over a sodium amalgam for 3 h. The anion was then added via a double-ended needle to a THF solution of the corresponding alkynyl tosylate at 0 °C. The reaction mixture was warmed to room temperature and stirred for 1 h. The solvent was removed under reduced pressure. Diethyl ether was added to the resulting residue, and the solution was filtered through celite. The diethyl ether was removed under reduced pressure. The crude product was purified by cold column chromatography (jacketed column with ice water recirculating through the jacket) on deactivated alumina.

2.8.1. Cyclopentadienyl-(3-(2′-chloro-1′-cyclohexenyl)-2-propynyl)-dicarbonyliron (17)

The iron anion was generated by stirring dicyclopentadienyl dicarbonyl iron (**16**) (3.81 g, 108.0 mmol) in THF over a 1% sodium amalgam (2.49 g, 108.0 mmol) for 5 h. The anion was then added to a solution of the 1-tosyl-3-(2′-chloro-2′-cyclohexenyl)-2-propyne (**8**) (7.02 g, 216.0 mmol) in THF using the procedure described above. The product (**17**) (2.051 g, 6.21 mmol, 58%) was purified via column chromatography (alumina, 20:1 pentane:ether). ^{1}H-NMR ($CDCl_3$) 4.80 (s, 5H), 2.28 (m, 2H), 2.18 (m, 2H), 1.72 (s, 2H) 1.63 (m, 2H), 1.51 (m, 2H). Anal. Calc. for $C_{16}H_{15}O_2FeCl$: C, 58.13; H, 4.57%. Found: C, 57.24; H, 4.72%.

2.8.2. Cyclopentadienyl(3-(4′-acetylphenyl)-2-propynyl)dicarbonyliron (18)

The iron anion was generated from $[CpFe(CO)_2]_2$ (0.939 g, 2.65 mmol) and then added to a solution of 1-tosyl-3-(4′-acetylphenyl)-2-propyne (**14**) (1.995 g, 6.08 mmol) in THF using the procedure described above. The resulting crude product was purified by jacketed cold column chromatography on deactivated alumina in 19:1 pentane:diethyl ether. The product (**18**) (1.02 g, 3.04 mmol, 58%) was a yellow brown solid. R_f: 0.41 (3:1 pentane:diethyl ether). M.p. 93–96 °C. IR (NaCl) 2015, 1961 cm^{-1}. ^{1}H-NMR ($CDCl_3$) 7.91 (d, $J = 7.9$ Hz, 2H), 7.31 (d, $J = 8.3$ Hz, 2H), 4.79 (s, 5H), 2.50 (s, 3H), 1.76 (s, 2H). ^{13}C-NMR ($CDCl_3$) 197.73, 135.04, 131.44, 131.16, 128.63, 106.80, 88.95, 86.42, 83.42, 26.87 (CO carbons not found). FAB HRMS (*m*/*z*) Calc. for $[M+H]^+$ ($C_{18}H_{15}O_3Fe$): 335.0371. Found: 335.0370.

2.8.3. Cyclopentadienyl(3-(4′-trifluoromethylphenyl-2-propynyl)dicarbonyliron (19)

The iron anion was generated from $[CpFe(CO)_2]_2$ (1.002 g, 2.83 mmol) and then added to a solution of 1-tosyl-3-(4′-trifluoromethylphenyl)-2-propyne (**15**) (2.000 g, 5.65 mmol) in THF using the procedure described above. The resulting crude product was purified by jacketed cold column chromatography on deactivated alumina in 100% pentane. The product (**19**) (0.677 g, 1.88 mmol, 33%) was a yellow brown solid. M.p. 51–53 °C. IR (KBr) 3208, 2988, 2016, 1963 cm^{-1}. ^{1}H-NMR ($CDCl_3$) 7.46 (m, 4H), 4.86 (s, 5H), 1.82 (s, 2H). ^{13}C-NMR ($CDCl_3$) 216.30, 132.09, 131.28, 130.08, 128.46, 125.45 (q, $J = 3.8$ Hz), 105.27, 86.29, 82.37, 68.28. FAB HRMS (*m*/*z*) Calc. for $[M+H]^+$ ($C_{17}H_{12}O_2Fe$): 361.0139. Found: 361.0135.

2.9. General procedure for synthesis of metallosulfinate esters

Following a literature procedure, [2d] the appropriate propargyl complex was dissolved in CH_2Cl_2 (15 ml) and degassed with nitrogen. Either SO_2 (1 M in $CHCl_3$) was added to the reaction mixture, or the reaction mixture was cooled to −78 °C and SO_2 (g) was bubbled through the reaction mixture for 5 min. The reaction was allowed to warm to room temperature, and stir overnight. The solvent was removed under reduced pressure, and the resulting solid was vacuum dried. The products were purified by cold column chromatography on silica gel.

2.9.1. Cyclopentadienyl(1-oxo-3-(4′-acetylphenyl)-1,2-oxathiol-3-enyl)dicarbonyliron (23)

Cyclopentadienyl(3-(4′-acetylphenyl)-2-propynyl)dicarbonyliron (**18**) (0.839 g, 2.52 mmol) was treated with SO_2 (g) as described above to generate the product (**23**) as a yellow brown solid (0.934 g, 2.347 mmol, 93%). M.p. 124–127 °C. IR (KBr) 2033, 1982, 1603 cm^{-1}. ^{1}H-NMR ($CDCl_3$) 8.02 (d, $J = 8.1$ Hz, 2H), 7.55 (d, $J = 8.1$ Hz, 2H), 5.57 (d, $J = 15.0$ Hz, 1H), 5.21 (d, $J = 15.0$ Hz, 1H), 4.79 (s, 5H), 2.65 (s, 3H). ^{13}C-NMR ($CDCl_3$) 213.13, 213.03, 197.76, 155.14, 150.41, 139.18, 136.66, 130.58, 128.50, 93.32, 85.50, 26.70. FAB HRMS (*m*/*z*) Calc. for $[M+H]^+$ ($C_{18}H_{15}O_5FeS$): 398.9990. Found: 398.9980.

2.9.2. Cyclopentadienyl(1-oxo-3-(4′-trifluoromethylphenyl)-1,2-oxathiol-3-enyl)dicarbonyliron (24)

Cyclopentadienyl(3-(4′-trifluoromethylphenyl)-2-propynyl)dicarbonyliron (**19**) (0.677 g, 1.880 mmol) was treated with SO_2 (g) for 5 min to generate the crude product. This product was then purified by cold column chromatography on silica gel in 3:1 ethyl acetate:pentane to yield a brown solid (**24**) (0.337 g, 0.968 mmol, 51%), M.p. 101–104 °C. IR (KBr) 2930, 2033, 1983, 1618, 1324, 1132 cm^{-1}. ^{1}H-NMR ($CDCl_3$) 7.70 (d, $J = 7.6$ Hz, 2H), 7.56 (d, $J = 7.5$ Hz, 2H), 5.56 (d, $J = 14.9$ Hz, 1H), 5.21 (d, $J = 14.9$ Hz, 1H), 4.79 (s, 5H). ^{13}C-NMR ($CDCl_3$) 213.49, 213.40, 155.69, 150.63, 138.36, 131.17, 125.90 (q, 3.6 Hz), 122.63, 93.74, 85.90 (qua-

ternary carbon α to CF_3 could not be located). Anal. Calc. for $C_{17}H_{11}F_3O_4SFe$: C, 48.14; H, 2.61%. Found: C, 48.15; H, 2.77%.

2.9.3. Cyclopentadienyl(1-oxo-3-(2′-chloro-1′-cyclohexenyl)-1,2-oxathiol-3-enyl)dicarbonyliron (25)

Cyclopentadienyl-(3-(2′-chloro-1′-cyclohexenyl)-2-propynyl)dicarbonyliron (**17**) (0.400 g, 1.21 mmol) was dissolved in freshly distilled CH_2Cl_2 (10 ml), and treated with SO_2 (g) as described above. The product (**25**) (0.093 g, 0.236 mmol, 20%) was isolated following silica chromatography (0 °C) (50:50 pentane:diethyl ether, then ether, then methanol). ^{1}H-NMR ($CDCl_3$) 5.38 (d, $J = 15$ Hz, 1H), 5.02 (d, $J = 16$ Hz, 1H), 4.94 (s, 5H), 2.42 (m, 2H), 2.30 (m, 2H), 1.75 (m, 2H), 1.68 (m, 2H). FAB HRMS Calc. for $[M+H]^+$ ($C_{16}H_{16}SO_4FeCl$): 394.9807. Found: 394.9807.

2.10. Procedure for synthesis of 4,5-diphenyl-3,6-dihydro-1,2-dithiin-1-oxide (26)

4,5-Diphenyl-3,6-dihydro-1,2-dithiin-1-oxide (**26**) was prepared in three steps using a procedure previously reported by our group [6]. Reported here are a new purification technique for 2,3-diphenyl-1,3-butadiene (**32**), and previously unreported ^{13}C-NMR data for 4,5-diphenyl-3,6-dihydro-1,2-dithiin-1-oxide (**26**).

2.10.1. ,3-Diphenyl-1,3-butadiene (32)

This compound was synthesized using a previously reported procedure [6] but the work-up was modified as described here. Cold pentane was added to a flask containing crude 2,3-diphenyl-1,3-butadiene (**32**). The resulting pale yellow solution was decanted from an orange oil that formed in the bottom of the flask. The solvent was then removed from the pale yellow solution under reduced pressure to yield 2,3-diphenyl-1,3-butadiene (**32**) identical to previously reported material by spectroscopic comparison [6].

2.10.2. 4,5-Diphenyl-3,6-dihydro-1,2-dithiin 1-oxide (26)

This compound was synthesized using a previously reported procedure [6]. Reported here is additional spectroscopic data for **26**. ^{13}C-NMR ($CDCl_3$) 140.99, 140.44, 138.90, 132.25, 129.59, 129.55, 128.63, 128.60, 127.87, 127.53, 62.09, 35.70.

2.11. General procedure for synthesis of metallothiosulfinate esters

In an adaptation of a literature procedure, [7] the appropriate propargyl complex (one equivalent) and 4,5-diphenyl-3,6-dihydro-1,2-dithiin 1-oxide (**26**) (1.5–1.8 equivalents) were dissolved in THF (50 ml). The reaction was stirred at 25 °C for 24 h. The solvent was removed under reduced pressure, and the crude product was purified by cold column chromatography.

2.11.1. Cyclopentadienyl(1-oxo-5-(4′-acetylphenyl)-1,2-dithiol-4-enyl)dicarbonyliron (28)

Cyclopentadienyl(3-(4′-acetylphenyl)-2-propynyl)dicarbonyliron (**18**) (0.318 g, 0.952 mmol) and 4,5-diphenyl-3,6-dihydro-1,2-dithiin 1-oxide (**26**) (0.409 g, 1.428 mmol) were dissolved in THF and allowed to react as described above. The reaction was stirred for 24 h to generate the crude product. The desired product was then isolated by cold column chromatography on silica gel using four column volumes of 1:9 diethyl ether:petroleum ether, two column volumes of 100% diethyl ether, and then 1:9 ethanol:diethyl ether to yield a brown solid (**28**) (0.220 g, 0.531 mmol, 56%), R_f: 0.28 (100% diethyl ether). M.p. 92–97 °C (decomposition). IR (KBr) 2031, 1982 cm^{-1}. ^{1}H-NMR ($CDCl_3$) 8.03 (d, $J = 8.1$ Hz, 2H), 7.55 (d, $J = 8.1$ Hz, 2H), 5.02 (d, $J = 16.5$ Hz, 1H), 4.76 (s, 5H),), 4.57 (d, $J = 16.5$ Hz, 1H), 2.26 (s, 3H). ^{13}C-NMR ($CDCl_3$) 213.37, 213.20, 197.85, 159.82 (not visible by ^{1}D-NMR, assigned via HMBC), 150.66, 141.37, 137.74, 131.80, 128.43, 85.85, 60.08, 26.75. FAB HRMS (*m*/*z*) Calc. for $[M+H]^+$ ($C_{18}H_{15}O_4S_2Fe_1$): 414.9761. Found: 414.9761.

2.11.2. Cyclopentadienyl(1-oxo-5-(4′-trifluoromethylphenyl)-1,2-dithiol-4-enyl-dicarbonyliron (29)

Cyclopentadienyl(3-(4′-trifluoromethylphenyl)-2-propynyldicarbonyliron (**19**) (0.436 g, 1.211 mmol) and 4,5-diphenyl-3,6-dihydro-1,2-dithiin 1-oxide (**26**) (0.624 g, 2.179 mmol) were dissolved in THF and allowed to react as described above. The reaction was stirred for 24 h to generate the crude product. The desired product was then isolated by cold column chromatography on silica gel using four column volumes of 1:9 diethyl ether:petroleum ether then 1:9 ethanol:diethyl ether to yield a brown solid (**29**) (0.318 g, 0.723 mmol, 60%), R_f: 0.22 (100% diethyl ether). M.p. 51–55 °C. IR (KBr) 2031, 1982 cm^{-1}. ^{1}H-NMR ($CDCl_3$) 7.72 (d, $J = 8.2$ Hz, 2H), 7.57 (d, $J = 8.3$ Hz, 2H), 5.01 (d, $J = 16.1$ Hz, 1H), 4.78 (s, 5H), 4.59 (d, $J = 16.4$ Hz, 1H). ^{13}C-NMR ($CDCl_3$) 213.70, 213.56, 160.55, 150.93, 132.33 (overlap of carbons *m* and *p* to CF_3 by HMBC), 130.95 (q, $J = 32.8$ Hz), 125.82 (q, $J = 3.6$ Hz), 86.32, 60.45 could not locate CF_3 carbon). Anal. Calc. for $C_{17}H_{11}F_3O_3S_2Fe$: C, 46.37; H, 2.52%. Found: C, 47.15; H, 2.77%. FAB HRMS (*m*/*z*) Calc. for $[M+H]^+$ ($C_{17}H_{12}O_3F_3S_2Fe$): 440.9529. Found: 440.9537.

2.11.3. Cyclopentadienyl(1-oxo-5-(1′-cyclohexenyl)-1,2-dithiol-4-enyl)-dicarbonyliron (30)

In a flame-dried flask under N_2, cyclopentadienyl-3-(1′-cyclohexenyl)-2-propynyldicarbonyliron (**20**) (0.331

g, 1.12 mmol) and **26** (0.400 g, 1.40 mmol) were allowed to react in THF (10 ml) as described above. The product (**30**) (0.266 g, 0.930 mmol, 83%) was isolated following silica chromatography (pentane then ether). ^{1}H-NMR ($CDCl_3$) 5.85 (s, 1H), 4.95 (s, 5H), 4.8 (d, $J = 16$ Hz, 1H), 4.35 (d, $J = 16$ Hz, 1H), 2.20 (m, 4H), 1.70 (m, 2H), 1.65 (m, 2H). ^{13}C-NMR ($CDCl_3$) 214.3, 214.0, 154.2, 133.9, 133.3, 129.0, 86.2, 59.3, 30.7, 26.1, 23.0, 21.9. IR ($CDCl_3$, cm^{-1}) 3170, 3025, 2985, 2940, 1645, 1550, 1470, 1390, 1315, 1280, 1215, 1170, 1095, 1040 cm^{-1}. Anal. Calc. for $C_{16}H_{16}O_3S_2Fe$: C, 51.07; H, 4.29%. Found: C, 50.62; H, 4.43%.

2.11.4. Cyclopentadienyl(1-oxo-5-(4′-methoxyphenyl)-1,2-dithiol-4-enyl)-dicarbonyliron (*31*)

In a flame-dried flask under N_2, cyclopentadienyl-3-(4′-methoxyphenyl)-2-propynyl-dicarbonyliron (**21**) (0.132 g, 0.410 mmol) and **26** (0.125 g, 0.437 mmol) were allowed to react in THF (10 ml) as described above. The product (**31**) (0.101 g, 0.251 mmol, 57%) was isolated following purification on silica eluting with pentane, then ether, then methanol. ^{1}H-NMR ($CDCl_3$) 7.31 (d, $J = 7.5$ Hz, 2H), 6.92 (d, $J = 7.5$ Hz, 2H), 4.94 (d, $J = 15.5$, 1H), 4.70 (s, 5H), 4.49 (d, $J = 15.5$, 1H), 3.81 (s, 3H). Anal. Calc. for $C_{17}H_{14}S_2O_4Fe$: C, 50.76; H, 3.51%. Found: C, 50.62; H, 3.54%.

2.12. General procedure for synthesis of sulfinate esters

In an adaptation of a literature procedure, [2d] the appropriate metallosulfinate ester was dissolved in distilled CH_2Cl_2, and in a separate flask ceric ammonium nitrate (four equivalents) was dissolved in HPLC grade methanol. The ceric ammonium nitrate solution was transferred to the metallosulfinate ester solution. The reaction was stirred at room temperature for 15–30 min. Water (20 ml) was added and extracted with ethyl acetate (3×20 ml). The organic layer was dried over $MgSO_4$, the solvent was removed under reduced pressure, and the resulting solid was vacuum dried. The products were purified by cold column chromatography on silica gel.

2.12.1. 4-(Carbomethoxy)-5-(4′-acetylphenyl)-1,2-oxathiol-4-en-1-yl oxide (*33*)

Cyclopentadienyl(1-oxo-3-(4′-acetylphenyl)-1,2-oxathiol-3-enyl)dicarbonyliron (**23**) (0.768 g, 1.930 mmol) in CH_2Cl_2 (50 ml) was treated with ceric ammonium nitrate (4.163 g, 7.594 mmol) in methanol (75 ml) for 15 min. The crude product was purified by chromatography on silica gel using 3:1 diethyl ether:pentane to yield the product (**33**) as a pale yellow oil (0.043 g, 0.154 mmol, 8%). R_f: 0.41 (3:1 diethyl ether: pentane). IR (KBr) 1729, 1687 cm^{-1}. ^{1}H-NMR ($CDCl_3$) 8.02 (d, $J =$ 8.4 Hz, 2H), 7.63 (d, $J = 8.4$ Hz, 2H), 5.93 (d, $J = 16.0$ Hz, 1H), 5.62 (d, $J = 16.0$ Hz, 1H), 3.75 (s, 3H) 2.63 (s, 3H). ^{13}C-NMR ($CDCl_3$) 197.27, 161.56, 155.62, 138.26, 132.08, 131.88, 129.33, 128.39, 83.07, 52.77, 26.70. HRMS (*m*/*z*) Calc. for [M^+] ($C_{13}H_{12}O_5FS$): 280.0405. Found: 280.0399.

2.12.2. 4-(Carbomethoxy)-5-(4′-trifluoromethylphenyl)-1,2-oxathiol-4-en-1-yl oxide (*34*)

Cyclopentadienyl(1-oxo-3-(4′-trifluoromethylphenyl)-1,2-oxathiol-3-enyl)dicarbonyliron (**24**) (0.400 g, 0.943 mmol) in CH_2Cl_2 (20 ml) was treated with ceric ammonium nitrate (2.131 g, 3.887 mmol) in methanol (30 ml) for 30 min. The crude product was purified by chromatography on silica gel using 1:1 diethyl ether:-pentane to yield the product as a pale yellow solid (**34**) (0.012 g, 0.039 mmol, 4%). R_f: 0.21 (1:1 diethyl ether: pentane). ^{1}H-NMR ($CDCl_3$) 7.72 (d, $J = 8.5$ Hz, 2H), 7.67 (d, $J = 8.4$ Hz, 2H), 5.94 (d, $J = 16.0$ Hz, 1H), 5.63 (d, $J = 16.0$ Hz, 1H), 3.76 (s, 3H). ^{13}C-NMR ($CDCl_3$) 161.48, 155.27, 131.91, 129.77 (overlap of carbons *m* and *p* to CF_3 by HMBC), 129.60, 125.14, 83.04, 52.65 (could not locate CF_3 carbon). HRMS (*m*/*z*) Calc. for $[M+H]^+$ ($C_{12}H_{10}O_4F_3S$): 307.0252. Found: 307.0241.

2.13. General procedure for synthesis of thiosulfinate esters

In an adaptation of a literature procedure, [7] the appropriate metallothiosulfinate ester was dissolved in distilled CH_2Cl_2 (6 ml) and HPLC grade methanol (16 ml). Ceric ammonium nitrate (four to eight equivalents) was then added. The reaction was stirred at room temperature for 15–30 min. Water (20 ml) was added and extracted with ethyl acetate (3×20 ml) or dichloromethane (3×20 ml). The organic layer was dried over $MgSO_4$, and the solvent was removed under reduced pressure.

2.13.1. 4-Carbomethoxy-5-(4′-acetylphenyl)-1,2-dithiol-4-en-1-yl oxide (*35*)

Cyclopentadienyl(1-oxo-5-(4′-acetylphenyl)-1,2-dithiol-4-enyl)dicarbonyliron (**28**) (0.124 g, 0.300 mmol) and ceric ammonium nitrate (0.661 g, 1.206 mmol) were stirred in CH_2Cl_2 and HPLC grade methanol for 30 min. The organic layer was extracted with ethyl acetate. The crude product was purified on a silica gel prep plate in 3:1 diethyl ether:pentane to yield a yellow oil (**35**) (0.021 g, 0.071 mmol, 24%), R_f: 0.27 (3:1 diethyl ether:pentane). IR (KBr) 1724, 1686 cm^{-1}. ^{1}H-NMR ($CDCl_3$) 7.99 (m, 2H), 7.54 (m, 2H), 5.17 (d, $J = 17.9$ Hz, 1H), 4.74 (d, $J = 17.9$ Hz, 1H) 3.67 (s, 3H), 2.63 (s, 3H). ^{13}C-NMR ($CDCl_3$) 197.33, 162.99, 157.83, 129.42, 128.71,

52.95, 46.54, 26.72. EI HRMS (*m/z*) Calc. for [M^+] ($C_{13}H_{12}O_4S_2$): 296.0177. Found: 296.0168.

2.13.2. 4-Carbomethoxy-5-(4′-trifluoromethylphenyl)-1,2-dithiol-4-en-1-yl oxide (**36**)

Cyclopentadienyl(1-oxo-5-(4′-trifluoromethylphenyl)-1,2-dithiol-4-enyl)dicarbonyliron (**29**) (0.065 g, 0.127 mmol) and ceric ammonium nitrate (0.488, 0.890 mmol) were stirred in CH_2Cl_2 and HPLC grade methanol for 30 min as described above. The residue was then dissolved in diethyl ether and filtered through a cotton plug to remove cerium salts. The solvent was removed under reduced pressure to yield a gum (**36**) (0.039 g, 0.121 mmol, 95%). R_f: 0.23 (1:1 diethyl ether:pentane). IR (KBr) 1720 cm^{-1}. ^{1}H-NMR ($CDCl_3$) 7.71 (d, $J = 8.23$ Hz, 2H), 7.55 (d, $J = 8.51$ Hz, 2H), 5.17 (d, $J = 18.1$ Hz, 1H), 4.74 (d, $J = 18.1$ Hz, 1H), 3.69 (s, 3H). ^{13}C-NMR ($CDCl_3$) 162.90, 157.49, 136.61, 134.11, 131.79, 129.47, 125.30, 122.52, 64.39, 52.75. EI HRMS (*m/z*) Calc. for [M^+] ($C_{12}H_9O_3F_3S_2$): 321.9945. Found: 321.9915.

2.13.3. 4-Carbomethoxy-5-(1′-cyclohexenyl)-1,2-dithiol-4-en-1-yl oxide (**37**)

Cyclopentadienyl(1-oxo-5-(1′-cyclohexenyl)-1,2-dithiol-4-enyl)dicarbonyliron (**30**) (0.118 g, 0.314 mmol) was dissolved in CH_2Cl_2 (10 ml) and purged with CO gas. Ceric ammonium nitrate (0.816 g, 1.57 mmol) was dissolved in methanol (15–20 ml) and also purged with CO gas and added to **30** as described above. The mixture was allowed to warm to 25 °C and stirred for 2 h under a balloon of CO. The product (**37**) (0.015 g, 0.058 mmol, 19%) was isolated following silica chromatography using a jacketed column (0 °C) (pentane then 50:50 pentane:diethyl ether). ^{1}H-NMR ($CDCl_3$) 5.95 (s, 1H), 4.95 (d, $J = 15$ Hz, 1H), 4.45 (d, $J = 15$ Hz, 1H), 3.75 (s, 3H), 2.11 (m, 4H), 1.68 (m, 2H), 1.58 (m, 2H). EI HRMS (*m/z*) Calc. for [M^+] ($C_{11}H_{14}O_3S_2$): 258.0384. Found: 258.0388.

2.13.4. 4-Carbomethoxy-5-(4′-methoxyphenyl)-1,2-dithiol-4-en-1-yl oxide (**38**)

Cyclopentadienyl(1-oxo-5-(4′-methoxyphenyl)-1,2-dithiol-4-enyl)dicarbonyliron (**31**) (0.030 g, 0.0746 mmol) was dissolved in CH_2Cl_2 (10 ml) and purged with CO gas. Ceric ammonium nitrate (0.327 g, 0.596 mmol) was dissolved in methanol (15–20 ml) and also purged with CO gas and added to **31** as described above. The mixture was allowed to warm to room temperature and stirred for 2 h under a balloon of CO. The product (**38**) (0.013 g, 0.0457 mmol, 61%) was purified on silica with 50:50 pentane:diethyl ether. ^{1}H-NMR ($CDCl_3$) 7.49 (d, $J = 7.5$ Hz, 2H), 6.89 (d, $J = 7.5$ Hz, 2H), 4.80 (d, $J = 15$ Hz, 1H), 4.28 (d, $J = 15$ Hz, 1H), 3.78 (s, 6H). IR ($CDCl_3$, cm^{-1}) 3155.1, 2985.4, 2901.8, 1734.0, 1652.9, 1602.8, 1559.0, 1473.7, 1380.1, 1296.8, 1248.3, 1216.3, 1172.6, 1095.8 cm^{-1}.

3. Results and discussion

3.1. Preparation of alkynyl complexes

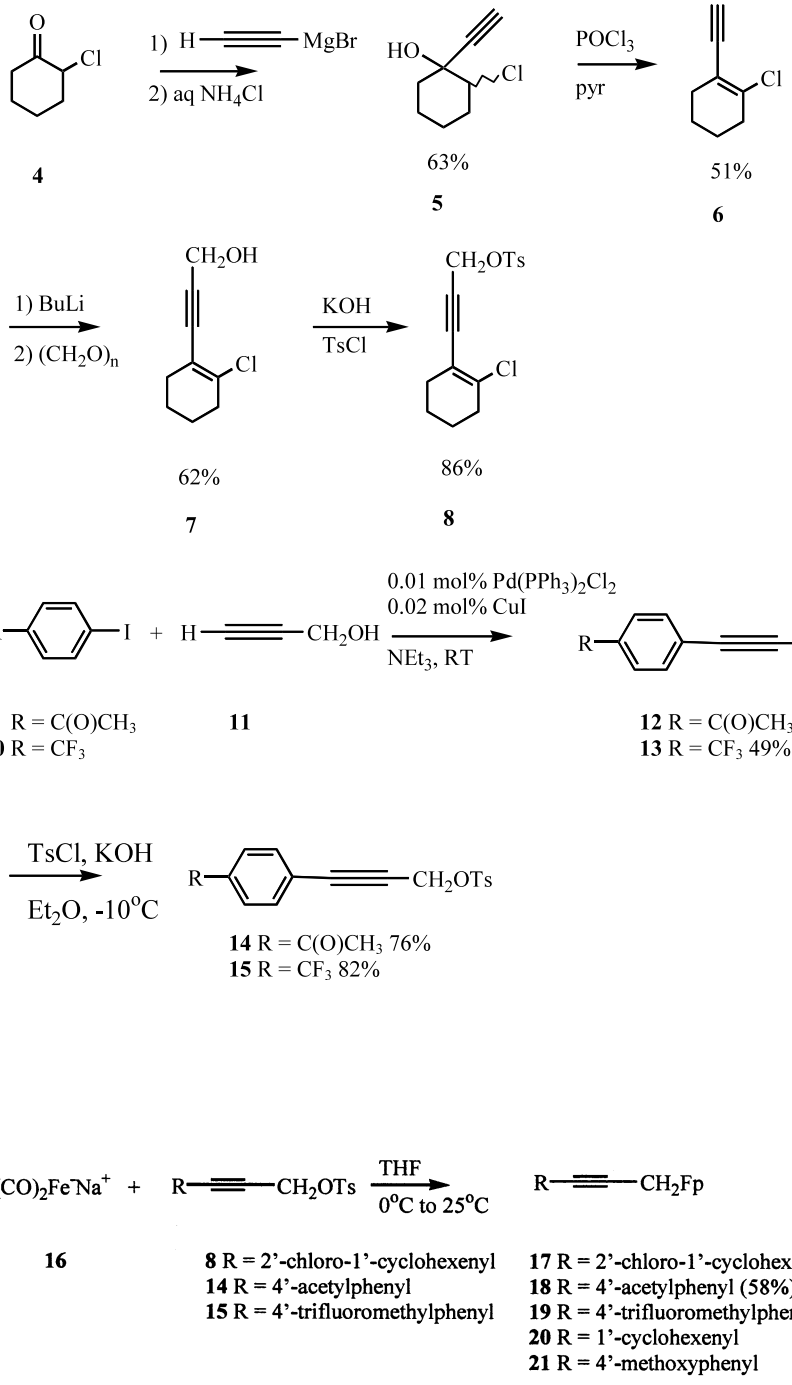
All alkynyl complexes used were synthesized via addition of a THF solution of the cyclopentadienyl iron dicarbonyl (Fp) anion to a THF solution of the appropriate 2-alkynyl tosylate. Many literature procedures [8] typically use 2-alkynyl halides but the tosylates are more convenient to work with since they are usually solids and many times produce higher yields of propargyl complex, presumably because they are less susceptible than the halides to reduction by the cyclopentadienyl iron dicarbonyl anion [2]. The cyclohexenyl and 4-methoxyphenyl substituted alkynyl complexes (**20** and **21**) used here have been reported previously by our group [2b].

Cyclohexenyl and phenyl substituted sulfur electrophiles were quite active in our initial anticarcinogenic enzyme induction and anti HIV-1 screens [5]. Increasing compound electrophilicity correlated with biological activity, so we were interested in the preparation of a halogen containing cyclohexene substituted propynyl electrophile and the preparation of phenyl propynyl electrophiles where the phenyl group was substituted with an electron withdrawing group.

The chlorocyclohexenyl substituted alkynyl tosylate (**8**) was prepared as described below. Ethynyl magnesium bromide was first added to 2-chlorocyclohexanone (**4**). The tertiary alcohol produced (**5**) was isolated as a 1:1 mixture of diastereomers and no attempt was made to separate them since the chiral centers were subsequently removed by dehydration using $POCl_3$/pyridine. The enyne (**6**) thus produced was deprotonated with BuLi and condensed with paraformaldehyde to produce propargyl alcohol (**7**). The alcohol (**7**) was converted to the tosylate (**8**).

Substituted phenyl propargyl alcohols (**12**–**13**) were prepared by Pd/Cu catalyzed cross-coupling of the appropriate aromatic iodide (**9**–**10**) with propargyl alcohol (**11**) [2d]. The substituted propargyl alcohols (**12**–**13**) were then converted to tosylates (**14**–**15**) in high yield [2d].

These substituted alkynyl tosylates (**8**, **14**, **15**) were then also treated with the cyclopentadienyl iron dicarbonyl anion (**16**) (Fp^-) to yield the iron alkynyl complexes (**17**–**19**) using a procedure analogous to one we [2d] and others [8] have reported previously. Alkynyl complexes (**20** and **21**) also used for cycloadditions here were reported previously [2d].

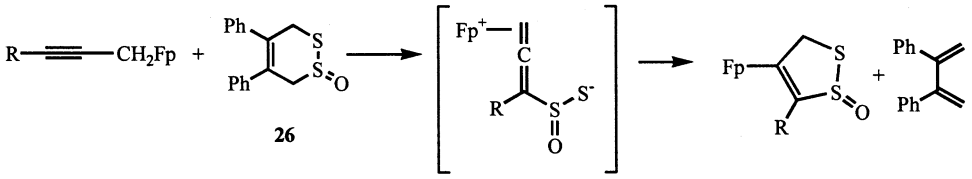


3.2. Cycloaddition reactions of alkynyl complexes with sulfur dioxide and disulfur monoxide and subsequent demetallation reactions of the cycloadducts

3.2.1. Cycloadditions with sulfur dioxide

The transition-metal mediated [3+2] cycloadditions of the iron alkynyl complexes (**17**–**19**) with sulfur dioxide were performed under conditions analogous to our prior work [2d]. These reactions are proposed to occur through a stepwise cyclization process involving an allene complex (**22**) [8]. The 4′-acetylphenyl substituted complex (**23**) was prepared in high yield (93%) and the 4′-trifluoromethylphenyl substituted complex (**24**) was prepared in good yield (51%). The reduction in yield

here is presumably due to the presence of the strongly electron withdrawing CF_3 group which may act to slow cyclization. The 2′-chloro-1′-cyclohexenyl complex (**17**) cyclized in surprisingly poor yield (20%) to produce **25**. The 1′-cyclohexenyl complex (**20**) had cyclized with SO_2 in 76% yield previously [2d] so the presence of the chloro group has had a large negative steric and/or electronic effect on the outcome of this cyclization. Diastereotopic ^{1}H-NMR methylene protons α to oxygen and diastereotopic ^{13}C-NMR metal carbonyls are characteristic spectroscopic signatures of all of these oxathiolene oxide complexes (**23**–**25**).



18 R = 4'-acetylphenyl
19 R = 4'-trifluoromethylphenyl
20 R = 1'-cyclohexenyl
21 R = 4'-methoxyphenyl

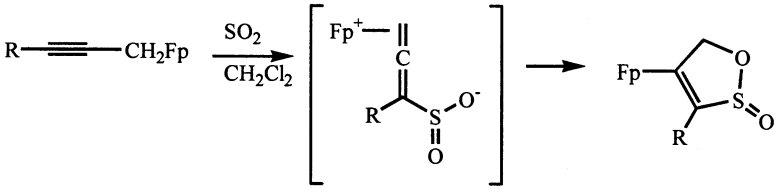
28 R = 4'-acetylPh (56%)
29 R = 4'-CF_3Ph (60%)
30 R = 1'-cyclohexenyl (83%)
31 R = 4'-MeOPh (57%)

3.2.2. Cycloadditions with disulfur monoxide

We have previously reported the preparation and use of 4,5-diphenyl-3,6-dihydro-1,2-dithiin-1-oxide (**26**) as a source of disulfur monoxide [6]. This compound (**26**) was prepared for use in these studies with slight modifications as described in Section 2. Disulfur monoxide source (**26**) is quite stable thermally and does not spontaneously undergo retro Diels-Alder reaction to liberate disulfur monoxide under the conditions used for the [3+2] cycloadditions reported here. Rather, we have proposed that these transition-metal alkynyl complexes (**18**–**21**) act as nucleophiles to drive a nucleophile induced electrocyclic ring opening reaction of **26**. This reaction would presumably generate an intermediate (**27**) analogous to **22** which cyclizes to produce the isolated dithiolene oxide complexes (**28**–**31**) in good yield. 2,3-Diphenyl-1,3-butadiene (**32**) can be recovered and reused in the preparation of **26** if desired. The oxathiolene oxide complexes (**28**–**31**) are surprisingly polar, requiring highly polar mobile phases for elution from silica, and have spectroscopic characteristics analogous to those described previously for **23**–**25**.

3.2.3. Demetallation reactions

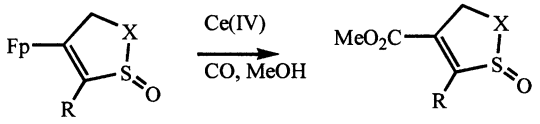
Organic compounds for biological testing were isolated by oxidative carbonylation of the iron substituted cycloadducts. Oxidative carbonylation adds a polar electron withdrawing group to the heterocycle and our earlier studies had shown this to be advantageous [5]. In general, we found oxidative carbonylation of oxathiolene oxide containing complexes (**23**–**25**) to be unsatisfactory, whereas yields for oxidative carbonylation of dithiolene oxides were much better. Oxathiolene oxides (**33**) and (**34**) from complexes (**23**) and (**24**) could only be isolated in 8 and 4% yields, respectively. Attempts to demetallate the chlorocyclohexenyl complex (**25**) using Ce(IV) for oxidative carbonylation or Me_2CuLi for reductive methylation [2] produced only small amounts of organic cycloadducts which could not be obtained in



17-19

23 R = 4'-acetylPh (93%)
24 R = 4'-CF_3Ph (51%)
25 R = 2'-Cl-1'-cyclohexenyl (20%)

quantities sufficient for characterization. We encountered some yield reductions in demetallations of oxathiolene oxides that we had reported previously [2d] but nothing this dramatic. The presence of the electron withdrawing substituents in these heterocycles must greatly accelerate competitive ring opening reactions to which these heterocycles are susceptible [9]. Yields for the production of dithiolene oxides (**35**–**38**) were generally much higher and we attribute this to their reduced susceptibility to ring opening in polar protic solvents.



23 X = O, R = 4'-acetylPh
24 X = O, R = 4'-CF_3Ph
28 X = S, R = 4² acetylPh
29 X = S, R = 4² CF_3Ph
30 X = S, R = 1² cyclohexenyl
31 X = S, R = 4² MeOPh

33 X = O, R = 4'-acetylPh, 8%
34 X = O, R = 4'-CF_3Ph, 4%
35 X = S, R = 4² acetylPh, 24%
36 X = S, R = 4² CF_3Ph, 95%
37 X = S, R = 1² cyclohexenyl, 19%
38 X = S, R = 4² MeOPh, 61%

4. Summary

In summary, we have extended metal alkynyl [3+2] cyclization reactions with SO_2 and S_2O to produce new iron substituted 1,2-oxathiolene-2-oxides and 1,2-dithiolene oxides. The [3+2] cycloaddition reactions of these metal substituted alkynyl complexes are not adversely affected by the presence of the electron withdrawing groups found in many of the alkynyl complexes we used. The iron substituted heterocycles can be demetallated but the presence of the electron withdrawing substituents was found to be extremely detrimental to the oxathiolene oxide demetallations. We will report on the biological activities of these new heterocycles in due course.

Acknowledgements

We thank the NIH NIGMS for their support. Low resolution mass spectra were obtained on instruments purchased with the partial support of NSF and the NC Biotechnology Center. The Duke University Center for Mass Spectrometry performed high resolution mass spectral analyses.

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