16 to 162 pM, respectively. The gel was loaded with a final volume of 40 μL in 10 mM Tris, 0.2 M KCl, 2.5% glycerol, 10 mM magnesium acetate, 0.3 mM dithiothreitol, 100 μg/mL salmon sperm DNA, and 50 μg/mL bovine serum albumin, pH 7.75. After electrophoresis, the gels were exposed to X-ray film overnight at −80 °C and scanned. The $K_{D(app)}$ for the *lac* wild-type and mutant repressors are 9.5×10^{-12} M and 30.6×10^{-12} M, respectively. (We believe this to be the first time PCR and a gel retardation assay have been used to measure protein–DNA dissociation constants in the picomolar concentration range.[28]) This is consistent with previous reports[6,7] that the tyrosine 7 to leucine mutant is a "weak binding" repressor.

While the mutation has significantly disrupted the overall structure and stability of the recognition helix, it appears to have had a lesser effect on DNA recognition and binding, suggesting that the operator may induce proper folding and stabilization of the recognition helix. Alternatively, the reduction in operator affinity may simply reflect the degree of helix disruption that we observe by NMR. Interestingly, the DNA recognition portion of the "bZIP" motif of GCN4 has been shown to increase in α-helical content in the presence of its target DNA.[36] If we are to understand the origin of protein–DNA recognition, it will be essential that we correlate biological functional changes with structural changes. Perhaps a certain degree of flexibility in the recognition helix will prove to be an important factor in the binding of proteins to DNA.

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Sulfur versus 2,3-η^2 Coordination of Benzo[*b*]thiophene (BT) in Cp′(CO)$_2$Re(BT)

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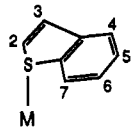
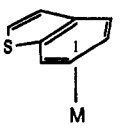
Recent studies of thiophene coordination and reaction in transition-metal complexes have suggested new modes of thiophene adsorption and activation on hydrodesulfurization (HDS) catalysts.[2,3] Much less is known about benzo[*b*]thiophene (BT) coordination in transition-metal complexes. Although there is one example of an S-bound BT complex, Cp(CO)$_2$Fe(*S*-BT)$^+$,[4] all other characterized complexes contain an η^6-BT ligand which is coordinated via the π-system of the benzene ring: CpRu(η^6-BT)$^+$,[5] Cp*Rh(η^6-BT)$^{+2}$,[5] Cp*Ir(η^6-BT)$^{+2}$,[5] and Cr(CO)$_3$(η^6-BT).[6]



S-BT



η^6-BT

However, η^6-binding to a metal site does not account for deuterium exchange or C–S bond cleavage of BT on HDS catalysts since the sites of deuterium exchange in BT are different over the catalyst and in CpRu(η^6-BT)$^+$.[7,8] In the present communication, we describe the complexes Cp′(CO)$_2$Re(BT), where Cp′ = η^5-C_5H_5 (Cp) or η^5-C_5Me_5 (Cp*), which exist as S- and 2,3-η^2-bound BT isomers in equilibrium with each other. The novel 2,3-η^2-BT bonding mode provides a basis for understanding initial steps in the hydrodesulfurization of BT.

A solution of Cp′(CO)$_2$Re(THF), generated by UV irradiation of a THF (30 mL) solution of Cp′Re(CO)$_3$ (0.20 g) at −20 °C,[9] was stirred with BT (0.30–0.40 g) at room temperature for 10 h. After removal of the solvent under vacuum, the residue was chromatographed on neutral alumina by using CH_2Cl_2/hexanes (1:4) as eluent. The yellow band was concentrated under vacuum and slowly cooled to −20 °C to give pale yellow, moderately air stable crystals of **1** (0.053 g, 21%) and **2** (0.071 g, 27%) respectively. Although elemental analyses and the mass spectrum establish the composition of **1** as Cp*(CO)$_2$Re(BT),[10] it is evident from the number of bands in the solution IR and ^{1}H and ^{13}C NMR spectra that it consists of two isomers, the η^2-bound (**1a**) and S-bound (**1b**) isomers, which are present at equilibrium in a 1.6:1 ratio in $CDCl_3$ solution at room temperature (Scheme I). The H2 and H3 ^{1}H NMR signals (δ 4.25, d; 3.96, d) of the BT in the major isomer (**1a**) are substantially upfield of those in free BT (δ 7.33 (H2) and 7.22 (H3)).[11] Also, two of the ^{13}C NMR resonances (δ 47.9 and 46.6),[10] presumably those of C2 and C3, are substantially upfield of those (δ 126.2 and 123.8)[11b] in BT. Such upfield ^{1}H and ^{13}C NMR shifts were observed previously in Cp*(CO)$_2$Re(η^2-selenophene)[12] and are characteristic of η^2-olefin[13] and η^2-arene[14] bonding. Thus, the major isomer (**1a**, Scheme I) contains 2,3-η^2-BT. This was further supported by an X-ray diffraction study[15] of a crystal of **1a** selected from product **1**.

The ^{1}H and ^{13}C NMR chemical shifts of the BT ligand in the minor isomer (**1b**)[10] are similar to those in free BT[11] (^{1}H NMR (CCl_4) δ 7.79, 7.72, 7.33, 7.26, 7.24, 7.22; ^{13}C NMR ($CDCl_3$) δ 139.7, 139.6, 126.2, 124.2, 124.1, 123.8, 123.6, 122.4), which are also similar to those[4] of the S-coordinated BT in Cp(CO)$_2$Fe(*S*-BT)$^+$. These comparisons together with the similarity of the ν(CO) bands (1932 and 1871 cm^{-1}) of **1b** and those (1934

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(10) **1**: EIMS (15 eV) *m/e* 512 (M$^+$ based on ^{187}Re), 456 (M$^+$ − 2CO), 378 (M$^+$ − BT), 350 (M$^+$ − (BT + CO)), 134 (BT). Anal. Calcd for $C_{20}H_{21}O_2ReS$: C, 46.95; H, 4.14. Found: C, 46.95; H, 4.13. **1a**: IR (hexanes) ν(CO) 1970 (s), 1908 (s) cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 7.5–7.1 (3 m, 4 H, BT), 4.25 (d, 1 H, BT), 3.96 (d, 1 H, BT), 2.02 (s, 15 H, Cp*); ^{13}C NMR ($CDCl_3$) δ 204.4 and 204.3 (CO), 125.5, 123.7, 123.2, 122.6, 47.9 and 46.6 (BT), 97.8 (C of Cp*), 10.2 (Me of Cp*). **1b**: IR (hexanes) ν(CO) 1932 (s), 1871 (s) cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 7.8–7.3 (4 m, 6 H, BT), 1.81 (s, 15 H, Cp*); ^{13}C NMR ($CDCl_3$) δ 205.5 (CO), 145.6, 137.8, 128.1, 126.7, 124.6 and 123.4 (BT), 95.9 (C of Cp*), 10.4 (Me of Cp*).
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(15) Details of the structure of **1a** will be published elsewhere.

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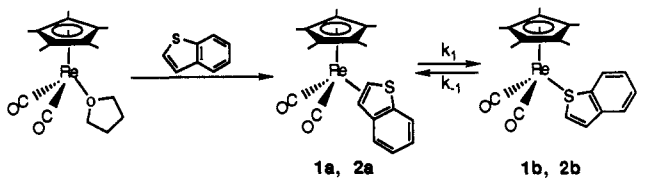
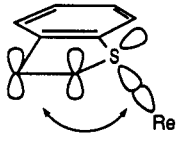
Scheme I



and 1874 cm^{-1}) of the S-bound thiophene complex $Cp^*(CO)_2Re(T)$[16] strongly suggest that **1b** contains an S-coordinated BT. Since all structures[3,17] of S-coordinated thiophene complexes contain pyramidal sulfur (approximately sp^3 hydridized), the sulfur in **1b** presumably has the same geometry.

Spectroscopic data[18] for the Cp analogue of **1**, $Cp(CO)_2Re(BT)$ (**2**), indicate that **2** also exists in solution as an equilibrium mixture of η^2 (**2a**) and S (**2b**) isomers, however, in a 1:3 ratio in $CDCl_3$ solvent at room temperature. Thus, the S-bound isomer is the major form of **2**, but the η^2-bound isomer predominates in **1**. The additional electron density provided by the Cp* ligand in **1** presumably reduces the Lewis acid character of the Re, which weakens the bond with the electron-donating sulfur in the S-bonded isomer (**1b**); at the same time, the higher electron density on Re increases π-back-bonding to the 2,3-η^2-olefinic bond of the BT ligand, which favors the η^2-bound isomer (**1a**).

The η^2-bound isomers (**1a** and **2a**) can be separated by hand from the S-bound isomers (**1b** and **2b**) on the basis of the morphology of the crystals. After the η^2-bound isomers were dissolved in CH_2Cl_2, rates of isomerization to the S-bound isomers at room temperture were determined by following the changes in intensity of the reactant and product CO bands until they reached equilibrium. The isomerization of **1a** ($k_1 = 9.0 \times 10^{-4}$, $k_{-1} = 15 \times 10^{-4}$ s^{-1}; $t_{1/2} = 13$ min for k_1) was approximately 8 times slower than that ($k_1 = 7.0 \times 10^{-3}$, $k_{-1} = 2.3 \times 10^{-3}$ s^{-1}; $t_{1/2} = 1.7$ min for k_1) of **2a**. These isomerizations must occur intramolecularly, since BT does not dissociate from either the η^2- or S-bound isomer during the time of the isomerization. This was shown by observing that no $Cp^*(CO)_2Re$(2-MeBT) formed when a $CDCl_3$ solution of $Cp^*(CO)_2Re(BT)$ (**1**) and 2-MeBT (2-methylbenzo[*b*]-thiophene) was stirred at room temperature for 26 h. Also there was no formation of $Cp^*(CO)_2Re(PPh_3)$ when **1** and PPh_3 were stirred in CD_2Cl_2 at room temperature for 24 h; at longer times (2 weeks) $Cp^*(CO)_2Re(PPh_3)$ was observed. The intramolecular interconversion of the η^2- and S-bound isomers presumably involves migration of the Re between sulfur and carbon orbitals on the same side of the BT ring.



These studies suggest that BT may coordinate to metal sites on HDS catalysts via either the sulfur or the C2-C3 olefin, and these S- and η^2-bound isomers may interconvert. Hydrogenation of BT could reasonably occur by insertion of the η^2 form into a metal hydride to give an alkyl intermediate, which would, with another hydride, reductively eliminate to give 2,3-dihydrobenzo[*b*]thiophene (DHBT). In fact, the homogeneous hydrogenation of BT to DHBT is catalyzed by complexes of Ru,[19,20] Os,[20] Rh,[20,21] and Ir[20] under mild conditions (85-175 °C). A similar process may also occur over heterogeneous HDS catalysts since much evidence[22-25] indicates that hydrogenation of BT to DHBT is the first step in an important pathway for the HDS of BT. Thus, the observed η^2-BT ligand in **1a** and **2a** provides for the first time a reasonable intermediate for understanding BT hydrogenation on HDS catalysts.

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One-Step Construction of the Stemodane Framework via the Cobalt-Catalyzed Cyclization of Monocyclic Enynes: A Formal Total Synthesis of Stemodin

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Aphidicolin (**1**)[1] and stemodin (**2**)[2] are members of a class of diterpenes that are attractive targets for total synthesis due to their unique spirocyclic constitution, numerous stereocenters, and biological activity.[3] The many synthetic approaches to the framework[4,5] have generally relied on classical strategies.[6] An

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