(dd, 1 H, J = 14, 8.3 Hz); MS m/z 220 (M^+), 185, 81, 69 (100), 57. Anal. Calcd for $C_{12}H_{12}O_2S$: C, 65.43; H, 5.49. Found: C, 65.16; H, 5.51.

3-*tert*-Butyl-3a,4,9,9a-tetrahydronaphtho[2,3-*b*]thiophene 1,1-Dioxide (20). A white solid: mp 155.5–156.5 °C; IR (KBr) 3074, 2970, 1603, 1457, 1272, 1127 cm^{-1}; ^1H NMR δ 7.30–7.12 (m, 4 H), 6.55 (s, 1 H), 3.64 (dd, 1 H, J = 18.1, 9.5 Hz); MS m/z 276 (M^+), 211, 185, 115, 57 (100). Anal. Calcd for $C_{16}H_{20}O_2S$: C, 69.53; H, 7.29. Found: C, 69.37; H, 7.29.

9,9a-Dihydronaphtho[2,3-*b*]thiophene 1,1-Dioxide (21). A white solid: mp 141–142 °C; IR (KBr) 3071, 2928, 1620, 1283, 1127 cm^{-1}; ^1H NMR δ 7.36–7.10 (m, 5 H), 6.90–6.76 (m, 2 H), 4.08 (ddd, 1 H, J = 12.7, 7.6, 2.5 Hz), 3.38–3.10 (m, 2 H); MS m/z 218 (M^+), 153 (100), 128, 115, 76; exact mass calcd for $C_{12}H_{10}O_2S$ 218.0402, found 218.0400. Anal. Calcd for $C_{12}H_{12}O_2S$: C, 66.03; H, 4.61. Found: C, 65.81; H, 4.60.

3,4:9,10-Dibenzo-12-chloro-6-thiadispiro[4.1.4.2]-3,9,12-tridecatriene 6,6-Dioxide (22). The purity of compound **22** was judged to be >95% by ^1H NMR spectral determination (see supplementary material): white solid; mp 172–173 °C; IR (KBr) 3058, 2950, 1609, 1422, 1302, 1140 cm^{-1}; ^1H NMR δ 7.35–7.15 (m, 8 H), 6.15 (s, 1 H), 3.99 (d, 2 H, J = 16.8 Hz), 3.95 (d, 2 H, J = 16.8 Hz), 3.44 (d, 2 H, J = 17.3 Hz), 3.12 (d, 2 H, J = 17.3 Hz); MS m/z 356 (M^+), 255 (100), 171, 131, 62; exact mass calcd for $C_{20}H_{17}ClO_2S$ 356.0638, found 356.0637.

Extrusion of Sulfur Dioxide from 3-Sulfolenes. Procedure A. To a suspension of $LiAlH_4$ (weight equal to weight of the sulfolene used) in anhydrous THF (10 mL/100 mg of $LiAlH_4$) was added a solution of 3-sulfolene **10c** or **18a–c** in THF (1 mL/100 mg of sulfolene). The mixture was stirred at room temperature for 12 h, and the excess of $LiAlH_4$ was destroyed by adding aqueous ether. The resulting solution was dried (Na_2SO_4), filtered, and evaporated under reduced pressure to give essentially pure dienyl product.

Procedure B. Sulfolene **10a** or **10b** (1 mmol) was thermolyzed at 180 °C in Kugehlrohr under vacuum (0.1 Torr) to give the analytically pure dienyl product.

2-Methyl-1,3-cycloheptadiene (23a). Obtained in 93% yield by procedure B from an unseparable mixture of **10a** and **11a** as a colorless oil: IR (neat) 2918, 1663, 1294, 1050 cm^{-1}; ^1H NMR δ 5.84–5.57 (m, 3 H), 2.35–2.14 (m, 4 H), 1.88–1.77 (m, 5 H); MS m/z 108 (M^+, 100), 93, 80; exact mass calcd for C_8H_{12} 108.0940 found 108.0935. Anal. Calcd for C_8H_{12}: C, 88.82; H, 11.18. Found: C, 88.51; H, 11.24.

2-Ethyl-1,3-cycloheptadiene (23b). A colorless oil: IR (neat) 2964, 1629, 1214, 1048 cm^{-1}; ^1H NMR δ 5.88–5.56 (m, 3 H), 2.33–2.15 (m, 4 H), 2.08–1.96 (m, 2 H), 1.87–1.75 (m, 2 H), 0.99 (t, 3 H, J = 7.5 Hz); MS m/z 122 (M^+, 100), 107, 93, 79; exact mass calcd for C_9H_{14} 122.1095, found 122.1083. Anal. Calcd for C_9H_{14}: C, 88.45; H, 11.55. Found: C, 88.24; H, 11.70.

2-*tert*-Butyl-1,3-cycloheptadiene (23c). A colorless oil: IR (neat) 2924, 1628, 1455 cm^{-1}; ^1H NMR δ 6.05–5.78 (m, 3 H), 2.10–1.85 (m, 6 H), 1.03 (s, 9 H); MS m/z 150 (M^+), 135, 107, 57 (100); exact mass calcd for $C_{11}H_{18}$ 150.1408, found 150.1391. Anal. Calcd for $C_{11}H_{18}$: C, 87.93; H, 12.07. Found: C, 87.50; H, 12.31.

6,7-Benzo-2-methyl-1,3,6-cyclooctatriene (24a). A colorless oil: IR (neat) 3012, 2931, 1637, 1428, 745 cm^{-1}; ^1H NMR δ 7.21–7.05 (m, 4 H), 6.15 (d, 1 H, J = 10 Hz), 5.77–5.62 (m, 1 H), 5.53–5.40 (m, 1 H), 3.38 (t, 4 H, J = 7.5 Hz), 1.81 (s, 3 H); MS m/z 170 (M^+), 155 (100), 142, 128, 115, 97; exact mass calcd for $C_{13}H_{14}$ 170.1096, found 170.1096. Anal. Calcd for $C_{13}H_{14}$: C, 91.71; H, 8.29. Found: C, 91.57; H, 8.35.

6,7-Benzo-2-ethyl-1,3,6-cyclooctatriene (24b). A colorless oil: IR (neat) 3012, 2964, 1651, 1426, 746 cm^{-1}; ^1H NMR δ 7.20–7.04 (m, 4 H), 6.19 (d, 1 H, J = 10 Hz), 5.82–5.67 (m, 1 H), 5.46 (t, 1 H, J = 7.7 Hz), 3.46–3.30 (m, 4 H), 2.16 (q, 2 H, J = 7.4 Hz), 1.06 (t, 3 H, J = 7.4 Hz); MS m/z 184 (M^+), 169, 155 (100), 128, 115, 91; exact mass calcd for $C_{14}H_{16}$ 184.1252, found 184.1242. Anal. Calcd for $C_{14}H_{16}$: C, 91.25; H, 8.75. Found: C, 90.98; H, 8.83.

6,7-Benzo-2-*tert*-butyl-1,3,6-cyclooctatriene (24c). A colorless oil: IR (neat) 3016, 2960, 1631, 1453, 1262 cm^{-1}; ^1H NMR δ 7.17–7.05 (m, 4 H), 6.37 (d, 1 H, J = 10 Hz), 5.81–5.68 (m, 1 H), 5.48 (t, 1 H, J = 7.7 Hz), 3.35 (d, 4 H, J = 7.7 Hz), 1.08 (s, 9 H); MS m/z 212 (M^+), 197, 169, 155 (100), 129, 115, 91; exact mass calcd for $C_{16}H_{20}$ 212.1565, found 212.1565. Anal. Calcd for $C_{16}H_{20}$: C, 90.51; H, 9.49. Found: C, 90.39; H, 9.62.

Acknowledgment. We thank the National Science Council of the Republic of China for financial support (NSC 79-0208-M001-10).

Registry No. **1**, 77-79-2; **6**, 627-31-6; **9a**, 1193-10-8; **9b**, 62157-91-9; **9c**, 62157-93-1; **9d**, 7311-87-7; **10a**, 133753-91-0; **10b**, 133753-92-1; **10c**, 133753-93-2; **11a**, 133753-94-3; **11b**, 133753-95-4; **11c**, 133753-96-5; **11d**, 133753-97-6; **12**, 133753-98-7; **13**, 133753-99-8; **14**, 133754-00-4; **17**, 91-13-4; **18a**, 133754-01-5; **18b**, 133754-02-6; **18c**, 133754-03-7; **18d**, 133754-04-8; **19a**, 133754-05-9; **19b**, 133754-06-0; **19d**, 133754-07-1; **19e**, 133754-08-2; **20**, 133754-09-3; **21**, 133754-10-6; **22**, 133754-11-7; **23a**, 14947-21-8; **23b**, 133754-12-8; **23c**, 51284-27-6; **24a**, 133754-13-9; **24b**, 133754-14-0; **24c**, 133754-15-1.

Supplementary Material Available: ^1H NMR spectra for compounds **11d**, **13**, **14**, **18d**, **19d**, and **22** (6 pages). Ordering information is given on any current masthead page.

Model Studies toward the Synthesis of Leukotrienes: Hetero-Diels–Alder Reactivity of Tricarbonyl(diene)iron Complexes

William A. Donaldson,*[1a] Chunlin Tao,[1a] Dennis W. Bennett,[1b,c] and Desiree S. Grubisha[1b]

Department of Chemistry, Marquette University, Milwaukee, Wisconsin 53233, and Department of Chemistry, University of Wisconsin—Milwaukee, Milwaukee, Wisconsin 53201

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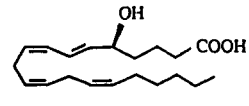
The application of (η^4-diene)$Fe(CO)_3$ complexes to organic synthesis has recently shown great promise due to their ease of preparation, resolution, and diastereoselective reactivity.[2] The possibility of utilizing these complexes for the synthesis of biologically interesting linear polyenes, such as the leukotrienes, has been reported.[3] In addition, we have found that (η^5-pentadienyl)$Fe(CO)_3$ cations may also prove useful for the preparation of the (*E,Z,Z*)-1,3,6-triene portion of the leukotrienes.[4] In order to develop routes for the further elaboration of these triene complexes into the HETEs,[5] we have investigated the hetero-Diels–Alder reaction[6] of (sorbaldehyde)$Fe(CO)_3$ (**1**) as a model system.[7,8]



5-HETE

(1) (a) Marquette University. (b) University of Wisconsin—Milwaukee. (c) Address correspondence concerning crystallographic analysis to this author.

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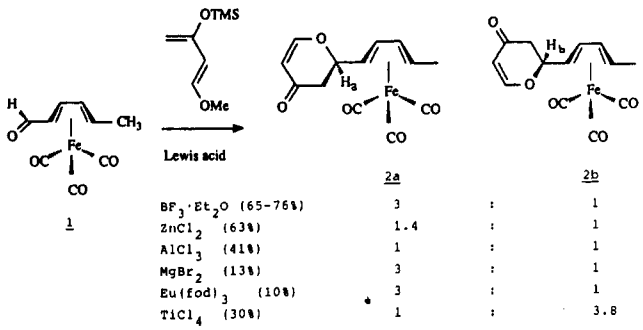
Scheme I



The reaction of **1** with 1-methoxy-3-[(trimethylsilyl)oxy]-1,3-butadiene, in the presence of $BF_3{\cdot}OEt_2$, followed by treatment with trifluoroacetic acid gave a separable mixture of dihydropyrone complexes **2a** and **2b** (65–76%, 3:1 ratio, Scheme I). The structural assignments for **2a** and **2b** (Ψ-exo and Ψ-endo respectively)[10] were tentatively based upon the relative chemical shifts of H_a and H_b.[11] However, the relative chromatographic mobility of **2a** and **2b** were opposite to that expected for Ψ-exo and Ψ-endo alcoholic isomers.[12] In order to unambiguously establish the relative stereochemistry, an X-ray analysis was preformed on **2b**.[13] This clearly established that **2b** possesses the Ψ-endo configuration (for an ORTEP of **2b**, see supplementary material).

A study of the diastereoselectivity of the cycloaddition was undertaken, with the results appearing in Scheme I. The highest yields and diastereoselectivity are observed with $BF_3{\cdot}OEt_2$ as the Lewis acid mediator. It is presumed that the major isomer, **2a**, arises from attack of 1-methoxy-3-[(trimethylsilyl)oxy]-1,3-butadiene on the carbonyl in the s-cis conformation, on the face opposite to the iron tricarbonyl adjunct. Notably, the diastereoselectivity can be reversed (i.e., Ψ-endo major) with the $TiCl_4$ as the Lewis acid.[2,14]

The cycloaddition reaction establishes a new asymmetric center adjacent to the coordinated diene, such as would be required for the HETEs. Elaboration of the dihydropyrones was accomplished by standard procedures (Scheme II). Thus, the reduction of **2a** or **2b** with DIBAL gave the diastereoisomeric allylic alcohols **3a** or **3b**, respectively. Ferrier rearrangement[15] of the separate allylic alcohols (*i*-PrOH, *p*-TsOH) gave the unsaturated cyclic acetals **4a** and **4b**. Hydrolysis of the acetals afforded the unsaturated lactols **5a** and **5b**, respectively. The Ψ-exo lactol **5a** readily underwent oxidation (PDC, 3-Å sieves)[16] to give the unsaturated lactone **6a**. The Ψ-endo lactol, however, gave a complex mixture of unidentified products, possibly containing ring-opened species. It might be speculated that the hydroxyl group of **5b** might be too sterically conjested for efficient formation of the chromate ester. Reduction of **6a** proved challenging; however, this could eventually be accomplished by the use of $Fe(CO)_5$/DABCO/DMF/H_2O[17] to afford the lactone **7a**. Comparison of the ^1H NMR spectrum of **7a** to those of the two diastereoisomeric diene lactone complexes prepared in the laboratory of Prof. M. Franck-Neumann indicate that the **7a** is identical with the compound previously assigned the 2*S**,5*R**,6*S** relative configuration.[18]

These steps constitute a synthetic methodology that should be applicable to the preparation of enantiomerically pure HETEs and iron-complexed HETEs.[19] Our efforts to couple this methodology to that which we have previously developed for the preparation of (*E*,*Z*,*Z*)-1,3,6-trienes, using (pentadienyl)$Fe(CO)_3$ cations,[4] will be reported in due course.

Experimental Section

General Data. Melting points were obtained using a Mel-Temp melting point apparatus and are uncorrected.

Unless noted, all reactions were carried out in flame-dried glassware under an atmosphere of nitrogen. Spectrograde solvents were used without further purification with the exception of diethyl ether and tetrahydrofuran, which were distilled from the sodium and potassium benzophenone ketyls, DMSO, which was refluxed over CaH_2 before distillation, and methylene chloride, which was distilled from phosphorus pentoxide. The ratio of diastereoisomeric mixtures **2a**:**2b** were determined by integration of the resonance signals for the H_4 protons (δ 4.06 and 4.21, respectively).

(7) The first Diels–Alder reaction of iron-complexed linear polyenes has recently been reported: Benvegnu, T.; Martelli, J.; Gree, R.; Toupet, L. *Tetrahedron Lett.* **1990**, *31*, 3145–8.

(8) It should be noted that racemic **1** was used as the starting material; therefore, all compounds described are racemic mixtures of enantiomers. Only one enantiomer has been diagrammed for clarity. However, the resolution of (diene)$Fe(CO)_3$ complexes has previously been accomplished.[9] Thus, in principle, this work could readily be applied to asymmetric synthesis.

(9) Franck-Neumann, M.; Martina, D.; Heitz, M. P. *Tetrahedron Lett.* **1982**, *23*, 3493–6. Monpert, A.; Martelli, J.; Gree, R.; Carrie, R. *Tetrahedron Lett.* **1981**, *22*, 1961–4.

(10) The Ψ-exo and Ψ-endo nomenclature was first used by Lillya: Clinton, N. A.; Lillya, C. P. *J. Am. Chem. Soc.* **1970**, *92*, 3058–64.

(11) It has been empirically observed that the resonance signal for the α-H of the Ψ-exo isomer, in general, appears upfield of that for the corresponding Ψ-endo isomer. See data contained in ref 8 and: Lellouche, J. P.; Breton, P.; Beaucourt, J. P.; Toupet, L.; Gree, R. *Tetrahedron Lett.* **1988**, *29*, 2449–52. Gree, R.; Laabassi, M.; Mosset, P.; Carrie, R. *Tetrahedron Lett.* **1984**, *25*, 3693–6. Lellouche, J. P.; Bulot, E.; Beaucourt, J. P.; Martelli, J.; Gree, R. *J. Organomet. Chem.* **1988**, *342*, C21–C25. This general trend holds for all diastereoisomeric pairs described in this manuscript.

(12) Gresham, D. G.; Lillya, C. P.; Uden, P. C.; Walters, F. H. *J. Organomet. Chem.* **1977**, *142*, 123–31.

(13) Compound **2b** crystallizes in the triclinical space group *P*1(2) with the following unit cell dimensions: a = 7.856 (1) Å, b = 11.202 (2) Å, c = 16.285 (3) Å, α = 105.871 (1)°, β = 95.56 (1)°, γ = 94.32 (1)°, V = 1364 (1) Å^3, and d_{calc} = 1.461 g/cm^3 for z = 4. There are two molecules per asymmetric unit. Reflections within a 2θ range of 5% < 2θ < 40% were collected with three check reflections every 120 min, yielding 2909 unique reflections of which 2289 were coded observed $I > 2\sigma(I)$. The structure was refined to R = 0.0484, R_w = 0.0502, $W = 1.0788/(\delta^2F + 0.001F^2)$.

(14) It should be noted that the Diels–Alder reaction reported by Martelli et al. (in which the iron complex acts as the dienophile) is completely diastereospecific.[7] For this reaction, the authors propose that the diene approaches the dienophile on the face opposite to the iron adjunct, in the s-trans conformation. This is due to the considerable steric bulk of the *gem*-diactivated olefin. While the present work is not as diastereoselective as that in ref 7, to make a comparison of these two reactions, as one reviewer has suggested, is unrealistic since the steric bulk of the carbonyl oxygen is entirely different than that of the *gem*-diactivated olefin terminus. In fact, the diastereoselectivity observed in our work is what would be expected for attack on coordinated dienal, as has been amply demonstrated for the nucleophilic attack on complex **1**.[2]

(15) Ferrier, J. P. *J. Chem. Soc.* **1964**, 5443–9.

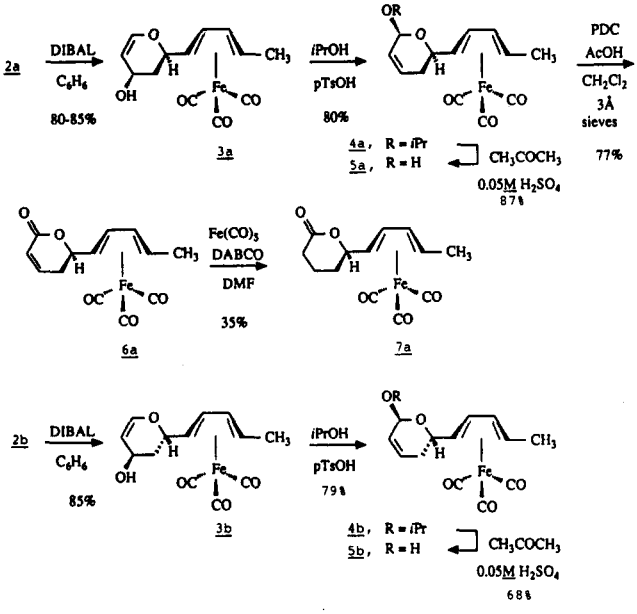
(16) Czernecki, S.; Georgoulis, C.; Stevens, C. L.; Vijayakumaran, K. *Tetrahedron Lett.* **1985**, *26*, 1699–1702.

(17) Noyori, R.; Umeda, I.; Ishigami, T. *J. Org. Chem.* **1972**, *37*, 1542–5. Boehm, M. F.; Prestwich, G. D. *J. Org. Chem.* **1987**, *52*, 1349–51. Ojima, I.; Kumagai, M.; Nagai, Y. *Tetrahedron Lett.* **1974**, *15*, 4005–8.

(18) Chemla, P. Doctoral Dissertation, Universite Louis Pasteur de Strasbourg, France, 1988. Compound **7a** and its C6 diastereoisomer have previously been prepared by acylation of (pentadiene)$Fe(CO)_3$ ($ClCOCH_2CH_2CH_2CO_2Me/AlCl_3$) followed by reduction ($NaBH_4$) and lactonization (*p*-TsOH). It should be noted that **7a** is the minor diastereoisomeric product in this sequence; the C6 diastereoisomer is the major product. Franck-Neumann, M. *Organometallics in Organic Synthesis*; de Meijere, A., tom Dieck, H., Eds.; Springer-Verlag: Berlin, 1987; p 247–64.

(19) The potential application of the iron tricarbonyl adjunct as an "IR marker" for the detection of complexed leukotrienes has previously been noted: Pinsard, P.; Lellouche, J. P.; Beaucourt, J. P.; Gree, R. *J. Organomet. Chem.* **1988**, *354*, 193–202.

Scheme II



Tricarbonyl[η^4-2,3-dihydro-2-(*E*,*E*)-1',3'-pentadienyl)-4-pyrone]iron (2a and 2b). To a solution of tricarbonyl(η^4-2,4-hexadienal)iron (1, 1.18 g, 5 mmol) and 1-methoxy-3-[(trimethylsilyl)oxy]-1,3-butadiene (1.15 g, 6 mmol) in dry ether (10 mL) at −78 °C was added dropwise, over a 10-min period, boron trifloride etherate (0.74 mL, 6 mmol). After 1.5 h, the reaction mixture was quenched by addition of saturated aqueous sodium bicarbonate (5 mL). The mixture was allowed to warm to 25 °C, diluted with brine (10 mL), and separated. The aqueous layers were extracted with ether (3 × 50 mL). The combined organic layers were washed with brine, dried, and concentrated. The residue was dissolved in CCl_4 (25 mL) and treated with trifluoroacetic acid (4 drops). When conversion of the acyclic products to pyrone was complete by TLC, the mixture was quenched with saturated aqueous sodium bicarbonate (1 mL) and worked up as in the previous text. The crude product was purified by column chromatography (SiO_2) using hexanes/ethyl acetate (10:1) as eluent to give a mixture of **2a** and **2b** (3:1) as a yellow solid (1.06 g, 67%). The mixture was separated by further chromatography (SiO_2) using pentane/ether (5:2) as eluent. Analytically pure samples of **2a** and **2b** were obtained by recrystallization from hexanes.

2a: R_f 0.40 (heptane/ether (5:2)); mp 119–120 °C; ^{1}H NMR ($CDCl_3$) δ 7.31 (d, J = 6.0, 1 H), 5.41 (d, J = 6.0, 1 H), 5.29 (dd, J = 7.8, 5.1, 1 H), 5.14 (dd, J = 8.4, 5.1, 1 H), 4.06 (ddd, J = 11.7, 8.4, 5.4, 1 H), 2.61 (m, 2 H), 1.46 (d, J = 6.0, 3 H), 1.37 (m, 1 H), 0.89 (t, J = 8.4, 1 H); ^{13}C NMR ($CDCl_3$) δ 210.2, 192.0, 163.0, 107.1, 87.6, 82.1, 82.0, 59.4, 56.3, 43.2, 19.2; IR (CH_2Cl_2) 2051, 1982, 1681, 1594 cm^{-1}. Anal. Calcd for $C_{13}H_{12}O_5Fe$: C, 51.35; H, 3.98. Found: C, 51.13; H, 3.86.

2b: R_f 0.28 (pentane/ether (5:2)); mp 84–85 °C; ^{1}H NMR ($CDCl_3$) δ 7.37 (d, J = 6.0, 1 H), 5.40 (d, J = 6.0, 1 H), 5.21 (dd, J = 8.1, 5.1, 1 H), 5.11 (dd, J = 8.7, 4.8, 1 H), 4.21 (ddd, J = 11.4, 7.5, 5.7, 1 H), 2.59 (m, 2 H), 1.44 (d, J = 6.0, 3 H), 1.22 (m, 1 H), 0.94 (t, J = 7.8, 1 H); ^{13}C NMR ($CDCl_3$) δ 210.5, 191.2, 163.1, 107.2, 86.4, 81.1, 79.9, 59.2, 58.4, 44.7, 19.1; IR (CH_2Cl_2) 2048, 1980, 1681, 1598 cm^{-1}. Anal. Calcd for $C_{13}H_{12}O_5Fe$: C, 51.35; H, 3.98. Found: C, 51.18; H, 3.98.

Cyclocondensation Catalyzed by $ZnCl_2$. To a solution of 1 (118 mg, 0.5 mmol) in dried THF (5 mL) was added anhydrous zinc chloride (1 mL, 0.1 M in ether, 1 mmol) under N_2 at room temperature, and the solution was stirred for 5 min. 1-Methoxy-3-[(trimethylsilyl)oxy]-1,3-butadiene (172 mg, 1.0 mmol) was added and the mixture stirred for 72 h at room temperature. Saturated aqueous sodium bicarbonate (1 mL) was added, and the mixture was extracted with ether (3 × 10 mL). The combined organic layers were dried ($MgSO_4$) and concentrated. The residue was dissolved in ether (5 mL), and trifluoroacetic acid (3 drops) was added. The solution was stirred for 1 h at room temperature. After evaporation of the solvent, the residue was chromatographed (SiO_2) with elution by hexanes/ethyl acetate (10:1). Evaporation of the product fraction gave a yellow crystalline solid (95 mg, 63%), which was determined to be a mixture of **2a** and **2b** (1.4:1) by ^{1}H NMR spectroscopy.

Cyclocondensation Catalyzed by $AlCl_3$. To a solution of 1 (250 mg, 2.06 mmol) in CH_2Cl_2 (10 mL) cooled to 0 °C was added 1-methoxy-3-[(trimethylsilyl)oxy]-1,3-butadiene (364 mg, 2.12 mmol) under N_2. The solution was stirred for 5 min, and $AlCl_3$ (283 mg, 2.12 mmol) was added. After the solution was stirred for 2.5 h, saturated aqueous sodium bicarbonate (2 mL) was added. The reaction mixture was extracted with ether (3 × 60 mL), dried ($MgSO_4$), and concentrated. The residue was dissolved in CCl_4 (8 mL) and treated by trifluoroacetic acid (10 drops) at room temperature for 1 h. The solution was evaporated to dryness. After chromatography (SiO_2) using hexanes/ethyl acetate (10:1) as eluent, a yellow crystalline solid (133 mg, 41%) was afforded. This was determined to be a mixture of **2a** and **2b** (1:1) by ^{1}H NMR spectroscopy.

Cyclocondensation Catalyzed by $MgBr_2$. To a solution of 1 (118 mg, 0.5 mmol) in THF (8 mL) cooled to 0 °C was added 1-methoxy-3-[(trimethylsilyl)oxy]-1,3-butadiene (172 mg, 1 mmol). The mixture was stirred for 10 min. Magnesium bromide (2 mL of a 0.50 M solution in 10% benzene/ether, 1.0 mmol) was added via syringe over a 5-min period, and the solution was allowed to warm slowly to room temperature. After stirring 100 h, the solution was poured into saturated aqueous sodium bicarbonate (1 mL) and extracted with ether (3 × 10 mL). The combined organic layers were dried ($MgSO_4$) and concentrated. The resultant oil was dissolved in CH_2Cl_2 (5 mL), and trifluoroacetic acid (10 drops) was added. After 1 h, the solution was concentrated in vacuo. Column chromatography (SiO_2) using hexanes/ethyl acetate (10:1) as eluent gave a yellow crystalline solid (20 mg, 13%). This was determined to be a mixture of **2a** and **2b** (3:1) by ^{1}H NMR spectroscopy.

Cyclocondensation Catalyzed by Eu(fod)$_3$. To a solution of 1 (118 mg, 0.5 mmol) and 1-methoxy-3-[(trimethylsilyl)-oxy]-1,3-butadiene (172 mg, 1.0 mmol) in $CHCl_3$ (8 mL) was added tris(6,6,7,7,8,8-heptafluoro-2,2-dimethyl-3,5-octanedionato)europium (26 mg, 0.005 mmol) under N_2 at room temperature. After the solution was stirred for 150 h, saturated aqueous sodium bicarbonate (0.5 mL) was added. The mixture was extracted with ether (3 × 50 mL), and the combined organic layers were dried ($MgSO_4$) and concentrated. The residue was dissolved in CCl_4 (8 mL), and trifluoroacetic acid (10 drops) was added. After 1 h, the solution was concentrated in vacuo. Chromatography (SiO_2) of the residue using hexanes/ethyl acetate (10:1) gave a yellow solid (18 mg, 10%). This was determined to be a mixture of **2a** and **2b** (3:1) by ^{1}H NMR spectroscopy.

Cyclocondensation Catalyzed by $TiCl_4$. To a cooled (−78 °C) solution of 1 (118 mg, 0.5 mmol) in CH_2Cl_2 (5 mL) was added $TiCl_4$ (0.5 mL, 0.5 mmol). The reaction mixture was stirred for 5 min, and 1-methoxy-3-[(trimethylsilyl)oxy]-1,3-butadiene (129 mg, 0.75 mmol) was added. The reaction mixture was stirred for 4 h at −78 °C. Saturated aqueous sodium bicarbonate (1 mL) was added, and the solution was warmed to room temperature. The mixture was extracted with ether (3 × 30 mL), and the combined organic layers were washed with brine, dried ($MgSO_4$), and concentrated. The residue was dissolved in CH_2Cl_2 (5 mL), and trifluoroacetic acid (3 drops) was added. The solution was stirred for 1 h. Saturated aqueous sodium bicarbonate (0.5 mL) was added, the mixture was extracted with ether (3 × 10 mL), and the combined extracts were concentrated. Column chromatography (SiO_2) using hexanes/ethyl acetate (10:1) as eluent afforded a yellow solid (46 mg, 30%). This was determined to be a mixture of **2a** and **2b** (1:3.8) by ^{1}H NMR spectroscopy.

Reduction of 2a. A solution of **2a** (284 mg, 0.93 mmol) in dry benzene (15 mL) was cooled (5 °C) under N_2. A solution of diisobutylaluminum hydride in toluene (1.87 mL, 1.87 mmol) was added dropwise via syringe. After 30 min, the reaction was quenched with methanol (1 mL). The mixture was poured into saturated aqueous Na_2SO_4 (10 mL) and extracted with ethyl acetate (3 × 80 mL). The combined organic layers were dried ($MgSO_4$) and concentrated to afford a yellow oil. Column chromatography (SiO_2) using hexanes/ethyl acetate (5:1) as eluent gave a yellow crystalline solid **3a** (230 mg, 81%). **3a**: mp 85–86 °C; ^{1}H NMR ($CDCl_3$) δ 6.31 (d, J = 6.0, 1 H), 5.23 (dd, J = 8.4,

5.0, 1 H), 5.09 (dd, J = 8.4, 5.0, 1 H), 4.74 (d, J = 6.0, 1 H), 4.42 (d, J = 0.6, 1 H), 3.62 (td, J = 9.0, 1.6, 1 H), 2.31 (dd, J = 13.4, 6.5, 1 H), 1.68 (m, 2 H), 1.42 (d, J = 6.0, 3 H), 1.29 (m, 1 H), 1.02 (t, J = 8.7, 1 H); IR (CH_2Cl_2) 2046, 1977 cm^{-1}; HRMS m/z 250.0288 (calcd for $C_{11}H_{14}O_2Fe$ (M - 2 CO) m/z 250.0291).

Reduction of 2b. A solution of **2b** (235 mg, 0.77 mmol) in dry benzene (15 mL) was cooled (5 °C) under N_2, and a solution of diisobutylaluminum hydride in toluene (1.55 mL, 1.55 mmol) was added dropwise. After 30 min, the reaction was quenched with methanol (1 mL). The workup was the same as for **3a**. A yellow oil (**3b**) was obtained (200 mg, 85%). **3b**: ^1H NMR ($CDCl_3$) δ 6.33 (d, J = 6.0, 1 H), 5.20 (dd, J = 8.7, 5.4, 1 H), 5.04 (dd, J = 9.0, 5.4, 1 H), 4.72 (br d, J = 6.0, 1 H), 4.42 (br s, 1 H), 3.88 (ddd, J = 11.3, 6.3, 1.8, 1 H), 2.26 (dd, J = 12.9, 6.6, 1 H), 1.63 (m, 2 H), 1.40 (d, J = 6.3, 3 H), 1.10 (m, 1 H), 0.96 (br t, J = 7.5, 1 H); IR (CH_2Cl_2) 2046, 1975 cm^{-1}; HRMS m/z 250.0306 (calcd for $C_{11}H_{14}O_3Fe$ (M - 2 CO) m/z 250.0291).

Ferrier Rearrangement of 3a. To a solution of **3a** (40 mg, 0.13 mmol) in isopropyl alcohol (5 mL) at 0 °C under N_2 was added p-toluenesulfonic acid (5 mg). The mixture was stirred at 0 °C for 8 h. The reaction mixture was poured into saturated aqueous sodium bicarbonate (1 mL). The reaction mixture was extracted with ether (3 × 10 mL), and the combined organic layers were washed with H_2O (1 mL) followed by brine (1 mL). The organic phase was dried ($MgSO_4$) and concentrated to yield a yellow oil, which was purified by column chromatography (SiO_2) using hexanes/ethyl acetate (20:1) as eluent to give a yellow crystalline solid (34 mg, 75%). **4a**: mp 37-38 °C (hexane); ^1H NMR ($CDCl_3$) δ 5.97 (dt, J = 10.3, 4.0, 1 H), 5.67 (ddd, J = 10.2, 5.0, 2.0, 1 H), 5.18 (dd, J = 8.2, 5.0, 1 H), 5.10-5.07 (m, 2 H), 4.05 (sept, J = 6.0, 1 H), 3.58 (td, J = 8.7, 7.3, 1 H), 2.09-2.02 (m, 2 H), 1.42 (d, J = 6.0, 3 H), 1.30 (d, J = 6.0, 3 H), 1.23 (m, 1 H), 1.18 (d, J = 6.0, 3 H), 0.85 (t, J = 8.5, 1 H); IR (CH_2Cl_2) 2046, 1980 cm^{-1}; HRMS m/z 348.0657 (calcd for $C_{16}H_{20}O_5Fe$ m/z 348.0657).

Ferrier rearrangement of 3b was performed in a fashion similar to the rearrangement of **3a** to **4a**. Column chromatography (SiO_2) using hexanes/ethyl acetate (20:1) as eluent afforded a yellow oil (180 mg, 79%). **4b**: ^1H NMR ($CDCl_3$) δ 5.99 (m, 1 H), 5.66 (dddd, J = 10.1, 3.0, 2.8, 1.6, 1 H), 5.22 (dd, J = 8.7, 5.0, 1 H), 5.08 (br s, 1 H), 5.03 (dd, J = 8.8, 5.0, 1 H), 4.09 (sept, J = 6.0, 1 H), 3.91 (dt, J = 10.5, 5.2, 1 H), 2.10-2.03 (m, 2 H), 1.40 (d, J = 6.0, 3 H), 1.26 (d, J = 6.0, 3 H), 1.19 (d, J = 6.0, 3 H), 1.09 (dqd, J = 9.0, 5.9, 0.8, 1 H), 0.99 (ddd, J = 8.9, 5.8, 0.8, 1 H); IR (CH_2Cl_2) 2043, 1972 cm^{-1}; HRMS m/z 348.0648 (calcd for $C_{16}H_{20}O_5Fe$ m/z 348.0657).

Hydrolysis of Cyclic Acetal 4a. To a solution of **4a** (210 mg, 0.60 mmol) in acetone (30 mL) was added 0.05 M H_2SO_4 (5 mL) under N_2 at room temperature. The solution was heated at reflux for 30 min. Saturated aqueous $NaHCO_3$ (10 mL) was added, and the mixture was extracted with ether (3 × 50 mL). The combined organic layers were dried ($MgSO_4$) and concentrated. Column chromatography (SiO_2) using hexanes/ethyl acetate (10:3) as eluent gave a yellow crystalline solid (160 mg, 87%). **5a**: mp 113-114 °C; ^1H NMR ($CDCl_3$) δ 5.96 (m, 1 H), 5.72 (m, 1 H), 5.34 (m, 1 H), 5.22 (dd, J = 8.4, 5.0, 1 H), 5.04 (ddd, J = 9.1, 5.0, 0.6, 1 H), 3.64 (ddd, J = 7.6, 7.6, 1 H), 2.85 (d, J = 5.0, 1 H), 2.23 (m, 2 H), 1.36 (d, J = 6.0, 3 H), 1.20 (m, 1 H), 0.83 (t, J = 8.2, 1 H); IR (CH_2Cl_2) 2043, 1967 cm^{-1}. Anal. Calcd for $C_{13}H_{14}O_5Fe$: C, 51.00; H, 4.61. Found: C, 51.22; H, 5.11.

Hydrolysis of Cyclic Acetal 4b. To a solution of **4b** (160 mg, 0.46 mmol) in acetone (10 mL) was added 0.05 M H_2SO_4 (0.8 mL) under N_2 at room temperature. The solution was stirred for 16 h and worked up in a manner similar to **5a** to afford a yellow crystalline solid **5b** (95 mg, 68%). **5b**: mp 97-98 °C; ^1H NMR ($CDCl_3$) δ 5.92 (m, 1 H), 5.71 (dddd, J = 10.1, 4.0, 2.8, 1.4, 1 H), 5.41 (m, 1 H), 5.11 (dd, J = 8.6, 5.0, 1 H), 4.99 (dd, J = 8.9, 5.0, 1 H), 3.73 (ddd, J = 9.1, 7.5, 4.9, 1 H), 2.53 (d, J = 4.4, 1 H), 2.05 (m, 2 H), 1.35 (d, J = 6.0, 3 H), 1.03 (dqd, J = 8.8, 6.0, 0.8, 1 H), 0.92 (t, J = 7.7, 1 H); IR (CH_2Cl_2) 2043, 1972 cm^{-1}. Anal. Calcd for $C_{13}H_{14}O_5Fe \cdot {}^1/_4H_2O$: C, 50.26; H, 4.70. Found: C, 50.08; H, 4.90.

Oxidation of Unsaturated Lactol 5a. To a solution of **5a** (60 mg, 0.2 mmol) and pyridinium dichromate (110 mg, 0.3 mmol) in CH_2Cl_2 (3 mL) was added freshly activated 3A molecular sieve powder (160 mg) and glacial acetic acid (1 drop). The solution was stirred until TLC showed no starting material remained (2-3 h). The mixture was extracted with ether (3 × 50 mL) and decanted. The combined organic solutions were washed successively with 0.5 M aqueous HCl (2 × 0.5 mL), saturated aqueous sodium bicarbonate solution (0.5 mL), and saturated aqueous sodium chloride (1 mL). The organic layer was dried ($MgSO_4$) and concentrated. Column chromatography (SiO_2) using hexanes/ethyl acetate (10:1) as eluent gave a yellow crystalline solid (46 mg, 77%). **6a**: mp 106-108 °C; ^1H NMR ($CDCl_3$) δ 6.88 (ddd, J = 9.9, 5.2, 3.5, 1 H), 6.02 (ddd, J = 9.9, 2.2, 1.6, 1 H), 5.25 (ddd, J = 7.9, 4.8, 0.8, 1 H), 5.17 (ddd, J = 8.4, 4.8, 1.0, 1 H), 4.07 (td, J = 9.4, 6.0, 1 H), 2.56 (m, 2 H), 1.44 (s, 3 H), 1.39 (m, 1 H), 0.90 (ddd, J = 9.6, 8.2, 1.0, 1 H); IR (CH_2Cl_2) 2049, 1985, 1723 cm^{-1}; HRMS m/z 304.0025 (calcd for $C_{13}H_{12}O_5Fe$ m/z 304.0033).

Reduction of Unsaturated Lactone 6a. A mixture of iron pentacarbonyl (168 mg, 0.86 mmol) and 1,4-diazabicyclo[2.2.2]-octane (48 mg, 0.43 mmol) in dimethylformamide/water (0.8 mL, 98:2 v/v) was flushed with N_2 and stirred for 5 min at room temperature. To the resulting dark red solution was added **6a** (65 mg, 0.21 mmol) in one portion. The mixture was allowed to stir at room temperature for 70 h. The mixture was treated with water (2 mL) and extracted with ether (3 × 15 mL). The combined extracts were washed with saturated aqueous sodium bicarbonate (3 × 0.5 mL) followed by saturated aqueous sodium sulfate (2 × 1 mL). The organic layer was dried ($MgSO_4$) and concentrated. The crude product was purified by column chromatography (SiO_2) using hexanes/ethyl acetate (20:3) as eluent to afford **7a** as a yellow oil (19 mg, 33%). **7a**: ^1H NMR ($CDCl_3$) δ 5.28 (ddd, J = 8.0, 5.0, 1.0, 1 H), 5.11 (dd, J = 8.6, 5.0, 1 H), 3.95 (ddd, J = 10.6, 9.4, 3.4, 1 H), 2.55 (dddd, J = 17.9, 6.4, 5.0, 1.2, 1 H), 2.39 (ddd, J = 17.7, 9.1, 6.8, 1 H), 2.06 (m, 1 H), 1.87 (m, 2 H), 1.65 (m, 1 H), 1.44 (d, J = 6.0, 3 H), 1.36 (dqd, J = 8.0, 6.2, 1.0, 1 H), 0.81 (ddd, J = 9.0, 8.0, 0.9, 1 H); IR (CH_2Cl_2) 2046, 1967, 1737 cm^{-1}; HRMS m/z 306.0175 (calcd for $C_{13}H_{14}O_5Fe$ m/z 306.0189). The ^1H NMR spectrum of compound **7a** was found to be identical with the spectrum of a sample generously provided by Prof. M. Franck-Neumann (Universite Louis Pasteur, Strasbourg).

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Supplementary Material Available: ORTEP of **2b**, and crystallographic data for **2b**, and ^{13}C NMR spectra of compounds **3a**, **3b**, **4a**, **4b**, and **6a** (12 pages). Ordering information is given on any current masthead page.

Convenient Method for the Titration of Amide Base Solutions

Robert E. Ireland* and Robert S. Meissner

Department of Chemistry, University of Virginia, Charlottesville, Virginia 22901

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Amide bases have become of crucial importance to many procedures in organic chemistry. Several amide base solutions are available commercially, such as metal diisopropylamides and hexamethyldisilazides,[1] but due to the

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