*Tetrahedron* Vol. 49, No. 39, pp. 8787-8794, 1993
Printed in Great Britain

0040-4020/93 $6.00+.00


# Reactivity of Carbon Nucleophiles with Disubstituted Tricarbonyl(pentadienyl)iron(1+) Cations: Application to the Synthesis of Lasiol and Epi-lasiol

**William A. Donaldson* and Myung-Jong Jin**

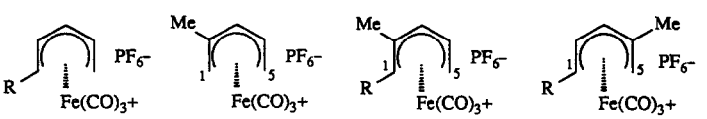
Department of Chemistry, Marquette University, Milwaukee, WI 53233 USA

(*Received in USA* 8 *July* 1993; *accepted* 2 *August* 1993)

*Key Words: (Pentadienyl)Fe(CO)$_3$ cations; C-C bond formation, terpene synthesis*

*Abstract* The reactions of 1,2-dimethyl-, 1-phenyl-2-methyl-, 1,4-dimethyl-, and 1-phenyl-4-methyl- substituted tricarbonyl(pentadienyl)iron(1+) cations (**3a**, **3b**, **4a**, **4b** respectively) with lithium dimethylcuprate and with sodium dimethylmalonate were examined. Regiospecific nucleophilic attack was observed in cases where the directing effects of the two substituents were matched. The reaction of **4a** with sodium dimethyl methylmalonate was examined, and the product was subsequently transformed into a mixture of epi-lasiol and lasiol, a terpene with a novel rearranged skeleton.

Addition of carbon nucleophiles to π-organometallic cations is of synthetic and theoretical interest. Where these reactions proceed with high regioselectivity, they have found great use in organic synthesis.[1] We and others have reported on the reactivity of monosubstituted (pentadienyl)Fe(CO)$_3$(1+) cations **1a**, **1b**, **1c**, and **2** with carbon nucleophiles.[2] These studies have indicated the regiochemical directing effects which can be expected for a single substituent. While there are two isolated reports of the reaction of malonate anion with (pentadienyl)Fe(CO)$_3$(1+) cations bearing multiple alkyl substituents,[3] the relative strengths of their directing effects has not been systematically explored. Recently, we have reported the synthesis of 1,2- and 1,4-disubstituted (pentadienyl)Fe(CO)$_3$(1+) cations **3a**, **3b**, **4a**, and **4b** and their reactivity with hetereoatom nucleophiles.[4,5] In this paper we describe the reactions of these cations with lithium dimethylcuprate and with sodium dimethylmalonate, and the use of cation **4a** in a short synthesis of the biogenetically novel terpene, lasiol.




**1a**, R = Me
**1b**, R = Ph
**1c**, R = $MeO_2C$

**2**

**3a**, R = Me
**3b**, R = Ph

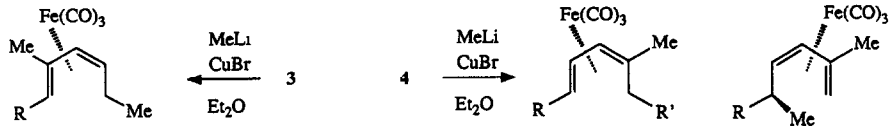
**4a**, R = Me
**4b**, R = Ph

## Results and Discussion[6]

Reaction of alkynylcuprates[2e] and functionalized cuprates[2i] with cations **1** proceeds via attack at the unsubstituted terminus, while reaction of 3-furylcuprate[2h] with **2** results in attack at C5. Thus it appears that

nucleophilic attack on (pentadienyl)$Fe(CO)_3$(1+) cations is controlled by steric influences. Dimethylcuprate was chosen for examination since its steric tolerance would test the limitations of the regioselectivity and since it was anticipated that the simplicity of the products would aid spectral interpretation.

For organocuprates, the substituents present on **3a** and **3b** have "matched" regiochemical directing effects. Thus, as expected, the reaction of cations **3a** and **3b** with MeLi, in the presence of $CuBr{\cdot}Me_2S$, each gave a single *E,Z*-diene complex, **5a** and **5b**, arising from attack at the unsubstituted terminus of the cisoid cation. Complex **5a** was identified by comparison to literature spectral data.[7] For complex **5b**, the signals at δ 5.13 (d, H3), 3.21 (s, H1), 2.48 (ddd, H4), and 1.02 (t, Me6) are particularly indispensable in its structural assignment.




**5a**, R = Me (92%)
**5b**, R = Ph (60%)

**6a**, R = R' = Me (1.8 . 1) **7a**, R = Me
**6b**, R = Ph, R' = Me (1 : 2) **7b**, R = Ph
**8a**, R = Me, R' = H (*Ref. 8*)
**8b**, R = Ph, R' = H (*Ref 4*)

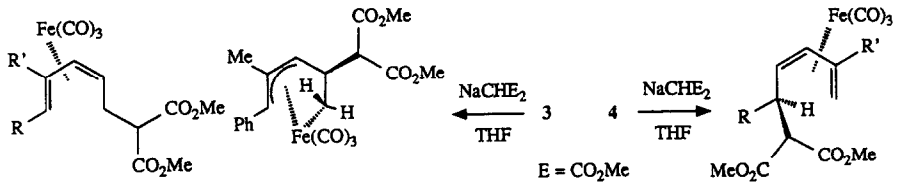
The substituent patterns present on cations **4a** and **4b** constitute "mismatched" regiochemical directing effects. The reaction of cations **4a** and **4b** with MeLi in the presence of $CuBr{\cdot}Me_2S$ each gave a mixture of products (**6a**:**7a**, 1.8:1 and **6b**:**7b**, 1:2 respectively). Further separation of these mixtures was not attempted.

The structural assignments of the products **6** - **7** are based on their $^1H$ NMR spectral data. In particular the triplet at δ 0.88 for **6a** and the triplet at δ 0.99 for **6b** correspond to the methyl groups which were introduced at the unsubstituted terminus. Additionally, the signals for H3, H4, 5-Me, and 1Me of **6a**, and the signals for H2, H4, H1, and 4-Me of **6b** match well with the corresponding proton signals of the known compounds **8a**[8] and **8b**.[4] The pair of doublets at δ 0.98 and 0.83 for **7a** correspond to the isopropyl group present, while the doublet at δ 1.21 of **7b** corresponds to the methyl group which was introduced at the substituted terminus. The chemical shifts for H4, H1*exo*, and H1*endo* of **7a** and **7b** (ca. 2.5, 1.9, and 1.6 ppm respectively) are characteristic of 2,4-disubstituted-1,3*Z*-diene complexes. It should be noted that the spectral data for **7a** are distinctly different from its known 3*E*-isomer.[9]

The steric bulk of a 4-methyl substituent is roughly balanced by that of a 1-methyl or 1-phenyl substituent. This may be contrasted to (4-triethylsilyl-1-methylpentadienyl)$Fe(CO)_3$(1+), in which the sterically bulky 4-triethylsilyl substituent directs addition exclusively at the substituted terminus.[5a]

Reaction of malonate anion with cation **1a** proceeds via attack at both the C1 and C5 termini, while reaction of malonate anion with **1b** occurs predominantly at the terminus bearing the phenyl substituent.[2d] This has previously been attributed to a combination of both steric and electronic influences. In comparison, malonate anion reacts with **2** by attack at the less hindered C5 terminus due to steric influences.[2h]

The reaction of **3a**, **4a**, and **4b** with dimethyl sodiomalonate each gave a single dimethyl (2Z,4-pentadien-1-yl)propanedioate complex (**9a**, **11a**, and **11b** respectively). The structures of these products were assigned by comparison to their $^1$H NMR spectral data with that of the known **12a**, **13a**, and **13b**.[2d] In comparison, the reaction of **3b** with dimethyl sodiomalonate gave a separable, 1 : 1 mixture of **9b** and **10**. The structure of **9b** was assigned by comparison of its $^1$H NMR spectral data with that of **5b**. Compound **10** was assigned as an $\eta^1,\eta^3$-allyl structure on the basis of its $^1$H NMR spectral data; in particular, the signals at $\delta$ 0.50 (dd) and -0.74 (t) ppm are characteristic of protons on a carbon $\sigma$-bound to iron.[2g,10]




**9a**, R = R' = Me, (62%)
**9b**, R = Ph, R' = Me (1·1)
**12a**, R = Me, R' = H (*Ref. 2d*)

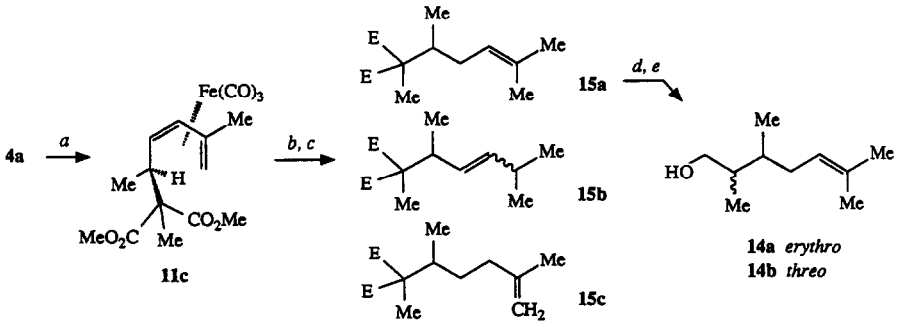
**10**

**11a**, R = R' = Me, (60%)
**11b**, R = Ph, R' = Me, (68%)
**13a**, R = Me, R' = H (*Ref. 2d*)
**13b**, R = Ph, R' = H (*Ref. 2d*)

For those cases where a single product is isolated, the substituent patterns present on the cations constitute either "matched" (**4b**) or "partially matched" (**3a** and **4a**) regiochemical directing effects.[11] For **3a** and **4a** the steric influence of the internal methyl substitutent (2-Me or 4-Me) suppresses any electronic or steric influence of the 1-methyl substituent. The substituent pattern present on **3b** is "mismatched"; the 2-methyl substituent should direct attack at C5 to afford the observed **9a**, while the 1-phenyl substituent should direct attack at C1. This latter product is not observed, but rather a product arising from attack at C4, an internal carbon, is observed. Attack by malonate anion at an internal site has previously been observed for (pentadienyl)-[2f,2j] and (cycloheptadienyl)Fe(CO)$_3$ cations[12] bearing an electron withdrawing substituent at either C1 or C3. We rationalize the formation of **10** in the following manner. It is speculated that in **3b** the plane of the 1-phenyl substituent is nearly perpendicular to the pentadienyl ligand due to the steric bulk of the adjacent 2-methyl substituent.[13] If this assumption is correct, then the phenyl substituent can not stabilize partial positive charge at C1 via resonance, and it acts as an inductively[14] electron withdrawing substituent.

**Synthesis of lasiol/epi-lasiol.** Lasiol (**14a**), a terpene with a biogenetically anomalous skeleton, was recently isolated from the mandibular gland of the male ant *Lasius meridionalis*.[15] Since cation **4a** reacts with malonate anion in a regiospecific fashion, a synthetic strategy which utilized this reactivity was conceived. Reaction of **4a** with dimethyl sodiomethylmalonate gave a single product (60%). The product was assigned structure **11c** by comparison of its $^1$H NMR spectral data with that of **11a**. Significantly, this involves the construction of a C-C bond between a tertiary and a quaternary carbon. Photolytic decomplexation of **11c** in acetic acid gave a mixture of olefins **15** (ca. 1:1:1, 75%). It should be noted that the photochemical reductive decomplexation of (diene)Fe(CO)$_3$ complexes is reported to be regioselective only when the complex bears

a terminal electron withdrawing substituent.[16] The mixture of olefins can be converted (pTsOH, $C_6H_6$, reflux) into a mixture predominating in the more substituted isomer **15a** (ca. 4:1:1, 95% mass recovery). The major olefin was separable by chromatography over $AgNO_3$ impregnated silica gel. Decarbomethoxylation (LiI·$3H_2O$, NaCN, DMF, reflux)[17], followed by reduction ($LiAlH_4$, $Et_2O$) gave a 1:1 mixture of lasiol and epi-lasiol (**14a** and **14b** respectively). The $^1H$ and $^{13}C$ NMR spectra of this synthetic mixture are identical with those kindly provided by Dr. T.H. Jones.




Scheme 1. Reagents: *a*, $NaCMeE_2$; *b*, hv/AcOH; *c*, pTsOH/$C_6H_6$/Δ; *d*, LiI/NaCN/DMF; *e*, $LiAlH_4$. E = $CO_2Me$

In summary, for cations **3** and **4**, in which the substituent directing effects are "matched" or "partially matched", addition of carbon nucleophiles proceeds in a *regiospecific* fashion. Where the directing effects are "mismatched", addition of carbon nucleophiles results in mixtures of products.

## EXPERIMENTAL SECTION

The pentadienyl cations **3a**, **3b**, **4a**, and **4b** were prepared by the literature procedures.[4]

**General Procedure for Reaction of Pentadienyl Cations with Dimethylcuprate.** To a solution of MeLi (ca. 1 mmol) in ether (20 mL) at -78 °C was added CuBr·$Me_2S$ (0.5 molar equivalent) and the mixture was stirred for 1 h. To the cold solution was added solid tricarbonyl(pentadienyl)iron(1+) hexafluorophosphate (0.4 molar equivalent) in one portion and the mixture was stirred at -78 °C for an additional 2 h. The solution was warmed to rt, diluted with saturated aqueous $NH_4Cl$ (15 mL) and $H_2O$ (15 mL), and extracted with ether (2 x 15 mL). The combined extracts were washed with $H_2O$ (25 mL), followed by brine (25 mL), dried ($MgSO_4$) and the solvent evaporated under reduced pressure. The residue was purified by chromatography (hexanes). The following compounds were prepared by this method.

**Tricarbonyl(3-Methyl-2*E*,4*Z*-heptadiene)iron (5a).** The product was isolated as a yellow oil (92%). 300-MHz $^1H$ NMR ($CDCl_3$) δ 5.04 (d, *J* = 8.0 Hz, H4), 2.31 (ddd, *J* = 6.0, 8.0, 14.3 Hz, H5), 2.22 (q, *J* = 6.6 Hz, H2), 2.15 (s, 3-Me), 1.47 (d, *J* = 6.6 Hz, Me1), 1.46 (m, H6), 1.24 (ddq, *J* = 14.3, 15.0, 7.3 Hz, H6'), 0.93 (t, *J* = 7.3 Hz, Me7). These values are identical with the literature data.[7]

**Tricarbonyl(2-methyl-1-phenyl-1*E*,3*Z*-hexadiene)iron (5b).** The product was isolated as a yellow oil (60%)

300-MHz $^1$H NMR ($CDCl_3$) δ 7.35-7.25 (m, ArH), 5.13 (d, *J* = 8.0 Hz, H3), 3.21 (s, H1), 2.48 (ddd, *J* = 6.5, 8.0, 8.0 Hz, H4), 2.36 (s, 2-Me), 1.67 (ddq, *J* = 8.0, 14.1, 7.2 Hz, H5), 1.46 (ddq, *J* = 6.5, 14.1, 7.2 Hz, H5'), 1.02 (t, *J* = 7.2 Hz, Me6); 75-MHz $^{13}$C NMR δ 211.6 (C≡O), 139.9, 129.9, 128.2, 126.3 (Aryl C), 107.4 (C2), 83.6 (C3), 64.1, 59.5 (C1, C4), 22.6, 20.6 (C5, 2-Me), 17.7 (C6). Anal. Calcd for $C_{16}H_{16}O_3Fe \cdot 1/6C_6H_{14}$: C, 62.53; H, 5.65. Found: C, 62.56; H, 5.34.

**Tricarbonyl(5-Methyl-2*E*,4*Z*-heptadiene)iron (6a) and Tricarbonyl(2,5-dimethyl-1,3*Z*-hexadiene)iron (7a).** The product was isolated as a yellow oil (73%). This was determined to be a 1.8:1 mixture of **6a** and **7a** by $^1$H NMR spectroscopy. Further separation of this mixture was not attempted. **6a**: 300-MHz $^1$H NMR ($CDCl_3$) δ 5.07 (dd, *J* = 5.2, 9.3 Hz, H3), 4.89 (d, *J* = 5.2 Hz, H4), 2.23 (dq, *J* = 9.0, 6.2 Hz, H2), 1.59 (m, H6), 1.53 (s, 5-Me), 1.44 (d, *J* = 6.2, Me1), 1.36 (dq, *J* = 14.8, 7.4 Hz, H6'), 0.88 (t, *J* = 7.4 Hz, Me7). **7a**: 300-MHz $^1$H NMR ($CDCl_3$) δ 5.06 (d, *J* = 7.9, H3), 2.31 (dd, *J* = 7.9, 9.8 Hz, H4), 2.13 (s, 2-Me), 1.93 (dd, *J* = 1.8, 2.6 Hz, H1*exo*), 1.41 (dd, *J* = 1.0, 2.6 Hz, H1*endo*), 1.26 (m, H2), 0.98 (d, *J* = 6.4 Hz, Me6), 0.83 (d, *J* = 6.4 Hz, Me6').

**Tricarbonyl(4-Methyl-1-phenyl-1*E*,3*Z*-heptadiene)iron (6b) and Tricarbonyl(2-methyl-5-phenyl-1,3*Z*-hexadiene)iron (7b).** The product was isolated as a yellow oil (92%). This was determined to be a 1:2 mixture of **6b** and **7b** by $^1$H NMR spectroscopy. Further separation of this mixture was not attempted. **6b**: 300-MHz $^1$H NMR ($CDCl_3$) δ 7.5-7.0 (m, ArH), 5.84 (dd, *J* = 5.5, 10.0 Hz, H2), 5.09 (d, *J* = 5.2 Hz, H4), 3.21 (d, *J* = 10.0, H1), 1.63 (m, H5, H5'), 1.61 (s, 4-Me), 0.99 (t, *J* = 7.3 Hz, Me6). **7b**: 300-MHz $^1$H NMR ($CDCl_3$) δ 7.5-7.0 (m, ArH), 5.23 (d, *J* = 7.7, H3), 2.77 (dd, *J* = 7.7, 10.3 Hz, H4), 2.21 (s, 2-Me), 2.30 (dq, *J* = 10.3, 6.6 Hz, H5), 1.93 (br s, H1*exo*), 1.84 (br s, H1*endo*), 1.21 (d, *J* = 6.6 Hz, Me6). EI-HRMS *m/z* 312.0450 (calcd for $C_{16}H_{16}O_3Fe$, 312.0447).

**General Procedure for Reaction of Pentadienyl Cations with Malonate Anion.** To a solution of sodium dimethylmalonate (ca. 0.5 mmol, freshly prepared from excess NaH and dimethylmalonate) in THF (25 mL) cooled to 0 °C was added solid pentadienyl cation (1 molar equivalent) in one portion. The reaction mixture was stirred for 1 h and then poured into saturated aqueous NaCl (50 mL) and extracted with ether (2 x 25 mL). The combined extracts were dried and the solvent evaporated under reduced pressure. The residue was purified by chromatography. The following compounds were prepared by this method.

**Tricarbonyl[dimethyl (4-methyl-2*Z*,4*E*-hexadien-1-yl)propanedioate]iron (9a).** The product was isolated as a yellow oil (62%), after chromatography (hexanes-ethyl acetate (9:1)). 300-MHz $^1$H NMR ($CDCl_3$) δ 5.02 (d, *J* = 7.3 Hz, H3), 3.73 (s, 2 x OMe), 3.29 (dd, *J* = 6.2, 8.5, C*H*($CO_2Me$)$_2$), 2.25 (q, *J* = 6.4 Hz, H5), 2.15 (m, H2), 2.13 (s, 4-Me), 1.72 (ddd, *J* = 8.5, 11.8, 15.6 Hz, H1), 1.47 (d, *J* = 6.4 Hz, Me6), 1.27 (m, H1'). EI-HRMS *m/z* 310.0510 (calcd for $C_{13}H_{18}O_5Fe$ (M - 2 CO) 310.0501).

**Reaction of 3b with sodium dimethylmalonate.** The product was isolated as a yellow oil (55%). This was determined to be a 1:1 mixture of **9b** and **10** by $^1$H NMR spectroscopy. Column chromatography (pentane-ether (19:1 to 7:1 gradient)) effected separation of the two products, with **10** eluting first as a yellow oil,

followed by **9b** as a yellow oil. **10**: 300-MHz $^1$H NMR ($CDCl_3$) δ 7.45-7.25 (m, ArH), 4.26 (s, H5), 4.11 (d, *J* = 7.3 Hz, H3), 3.76 (s, OMe), 3.70 (s, OMe), 3.47 (m, H2), 3.18 (d, *J* = 11.3 Hz, C*H*($CO_2Me$)$_2$), 1.79 (s, 4-Me), 0.50 (dd, *J* = 8.7, 10.7 Hz, H1), -0.74 (t, *J* = 8.7 Hz, H1'). EI-HRMS *m/z* 372.0667 (calcd for $C_{18}H_{20}O_5Fe$ (M - 2 CO) 372.0657). **9b**: 300-MHz $^1$H NMR ($CDCl_3$) δ 7.4-7.2 (m, ArH), 5.11 (d, *J* = 7.7 Hz, H3), 3.75 (s, 2 x OMe), 3.38 (dd, *J* = 6.0, 8.4, C*H*($CO_2Me$)$_2$), 3.20 (s, H1), 2.35 (s, 4-Me), 2.32 (m, H2), 1.95 (ddd, *J* = 8.4, 10.9, 15.4 Hz, H1), 1.26 (m, H1'). EI-HRMS *m/z* 372.0654 (calcd for $C_{18}H_{20}O_5Fe$ (M - 2 CO) 372.0657).

**Tricarbonyl[dimethyl (5-methyl-3*Z*,5*E*-hexadien-2-yl)propanedioate]iron (11a).** The product was isolated as a yellow oil (60%), after chromatography (hexanes-ethyl acetate (4:1)). 300-MHz $^1$H NMR ($CDCl_3$) δ 5.02 (d, *J* = 7.9 Hz, H4), 3.72 (s, OMe), 3.70 (s, OMe), 3.15 (d, *J* = 8.1, C*H*($CO_2Me$)$_2$), 2.23 (m, H3), 2.15 (s, 5-Me), 1.97 (br s, H1*exo*), 1.85 (m, H2), 1.46 (br s, H1*endo*), 1.10 (d, *J* = 6.2 Hz, Me1). Anal. Calcd for $C_{15}H_{18}O_7Fe \cdot \frac{1}{6}C_6H_{14}$: C, 51.71; H, 5.78. Found: C, 51.52; H, 5.41.

**Tricarbonyl[dimethyl (4-methyl-1-phenyl-2*Z*,4*E*-pentadien-1-yl)propanedioate]iron (11b).** The product was isolated as a yellow oil (68%), after chromatography (hexanes-ethyl acetate (9:1)). 300-MHz $^1$H NMR ($CDCl_3$) δ 7.25 (m, 3H, ArH), 7.10 (m, 2H, ArH), 5.16 (d, *J* = 7.4 Hz, H3), 3.80 (s, OMe), 3.64 (d, *J* = 10.1, C*H*($CO_2Me$)$_2$), 3.39 (s, OMe), 2.82 (dd, *J* = 10.1, 11.5, H1), 2.62 (dd, *J* = 7.4, 11.5 Hz, H2), 2.17 (s, 4-Me), 1.93 (dd, *J* = 1.2, 3.0, H1*exo*), 1.73 (d, *J* = 3.0, H1*endo*); 75-MHz $^{13}$C NMR δ 209.7 (C≡O), 168.1, 167.3 ($CO_2R$), 141.7, 128.4, 127.6, 127.3 (Aryl C), 109.5 (C4), 84.6 (C3), 62.3 (C2), 56.8 (*C*H($CO_2R$)$_2$), 52.5 (OMe), 52.2 (OMe), 43.8, 43.5 (C1, C5), 24.2 (C1). EI-HRMS *m/z* 372.0672 (calcd for $C_{18}H_{20}O_5Fe$ (M - 2 CO) 372.0657).

**Tricarbonyl[dimethyl methyl(5-methyl-3*Z*,5*E*-hexadien-2-yl)propanedioate]iron (11c).** Dimethyl methylmalonate was used instead of malonate, and the reaction was performed on a 3.76 mmol scale. After chromatography ($C_6H_6$), the product was isolated as a golden yellow oil (60%). Rf = 0.51 ($C_6H_6$); 300-MHz $^1$H NMR ($CDCl_3$) δ 4.90 (d, *J* = 7.8 Hz, H4), 3.57 (s, OMe), 3.56 (s, OMe), 2.11 (dd, *J* = 7.8, 11.5 Hz, H3), 2.03 (s, 5-Me), 1.83 (br s, H6*exo*), 1.80 (m, H2), 1.37 (dd, *J* = 1.0, 2.8 Hz, H6*endo*), 1.23 (s, Me), 0.95 (d, *J* = 6.4 Hz, Me1); 75-MHz $^{13}$C NMR δ 211.4 (C≡O), 172.1 ($CO_2R$), 109.5 (C5), 86.2 (C4), 60.6, 59.7 (C3, *C*Me($CO_2R$)$_2$), 52.8 (OMe), 52.7 (OMe), 44.4 (C6), 37.6 (C2), 24.8 (5-Me), 19.3 (C1), 16.2 (Me). EI-HRMS *m/z* 324.0662 (calcd for $C_{14}H_{20}O_5Fe$ (M - 2 CO) 324.0657).

**Dimethyl methyl(5-methyl-4-hexen-2-yl)propandioate (15a).** A degassed solution of **11c** (0.86 g, 2.26 mmol) in acetic acid (100 mL) in a 3 cm x 20 cm cylindrical pyrex flask, under $N_2$, was irradiated intermitantly with a 450W Hg lamp, for a total of 24 h. The dark orange-brown solution was poured into $H_2O$ (200 mL) and extracted with petrol ether (4 x 50 mL). The combined extracts were washed with $H_2O$ (100 mL), dilute aqueous $NaHCO_3$ (100 mL), and finally $H_2O$ (100 mL), dried ($MgSO_4$), and the solvent evaporated. Analysis of the crude product (0.41 g) by GC/MS and $^1$H NMR spectroscopy indicated a mixture of 3 olefins (ca. 1:1:1 ratio). The mixture was dissolved in $C_6H_6$ (50 mL) and p-toluenesulfonic acid (0.06 g) was added.

The mixture was heated at a gentle reflux for 6 h. The reaction mixture was cooled to rt, diluted with petrol ether (50 mL), washed with saturated aqueous $NaHCO_3$ (2 x 30 mL), dried ($MgSO_4$), and the solvent evaporated. Analysis of the crude product by GC/MS and $^1H$ NMR spectroscopy indicated a mixture of olefins, with the desired **15a** as the major component (ca. 65%). Chromatography over 10% $AgNO_3$ impregnated $SiO_2$ (200+ mesh) (hexanes-ethyl acetate (50:1)) gave pure **15a** as a colorless oil. IR (neat) 1724 $cm^{-1}$; 300-MHz $^1H$ NMR ($CDCl_3$) δ 5.08 (ddhept, $J$ = 6.6, 7.8, 1.4 Hz, H4), 3.68 (s, OMe), 3.67 (s, OMe), 2.28 (ddq, $J$ = 3.2, 10.2, 6.8 Hz, H2), 1.98 (br dd, $J$ = 6.1, 13.3 Hz, H3), 1.74 (m, H4'), 1.66 (br s, Me6), 1.56 (br s, Me6'), 1.33 (s, Me), 0.82 (d, $J$ = 6.8 Hz, Me1); 75-MHz $^{13}C$ NMR ($CDCl_3$) δ 172.3 ($CO_2R$), 132.9 (C5), 122.8 (C4), 57.8 ($CMe(CO_2R)_2$), 52.3 (OMe), 38.3, 30.8, 25.8 (C3, C6, C6'), 17.7, 15.7, 14.6 (C1, C2, Me). GC/MS *m/z* 151 (11), 146 (79), 114 (72), 96 (100), 81 (61), 69 (32), 59 (39), 55 (57), 41 (98). FAB-HRMS *m/z* 243.1585 [calcd for $C_{13}H_{23}O_4$ (M+1) 243.1590].

**Lasiol (14a) and epi-Lasiol (14b).** To a solution of **15a** (30.0 mg, 0.124 mmol) in DMF (35 mL) was added NaCN (0.05 g) and $LiI{\cdot}3H_2O$ (0.05 g). The mixture was heated, with stirring, to 120 °C for 24 h. The reaction mixture was cooled to rt, diluted with $H_2O$ (50 mL) and extracted with $CH_2Cl_2$ (2 x 30 mL). The combined extracts were washed with 10% aqueous HCl (20 mL), followed by saturated aqueous $NaHCO_3$ (50 mL), dried ($MgSO_4$) and the solvent evaporated. The residue was taken up in hexanes (50 mL) and washed with $H_2O$ (35 mL), dried ($MgSO_4$) and the solvent evaporated. The residue was taken up in ether (5 mL) and added dropwise to a suspension of $LiAlH_4$ (0.01 g, 0.26 mmol) in ether (4 mL) at rt. The mixture was stirred for 2 h. Water (5 drops) was cautiously added, followed by 0.2 N NaOH (10 drops) and finally water (5 mL). The layers were separated and the aqueous layer was extracted with ether (2 x 5 mL). The combined ethereal fractions were dried ($MgSO_4$) and the solvent evaporated to afford a colorless oil: 9.1 mg, 0.058 mmol, 47%. **14a/b**: 300-MHz $^1H$ NMR ($CDCl_3$) δ 5.11 (br t, $J$ = 6.8, H5), 3.65 (dd, $J$ = 5.1, 10.7, H2 **14a**), 3.55 (dd, $J$ = 6.3, 10.5, H2 **14b**), 3.46 (m, H2' **14a/b**), 2.1-1.7 (m), 1.69 (s, Me7), 1.59 (s, Me7'), 0.92 and 0.86 (2 x d, $J$ = 6.8, 2 x Me **14a**), 0.82 and 0.78 (2 x d, $J$ = 6.8, 2 x Me **14b**); 75-MHz CMR ($CDCl_3$) **14a**: δ 132.1, 123.5, 66.1, 40.2, 35.5, 31.3, 25.8, 17.0, 13.8; **14b**: δ 132.1, 123.5, 66.9, 39.0, 34.1, 33.3, 25.8, 17.8, 14.4, 11.4.

**Acknowledgments**: Financial support for this work was provided by National Institutes of Health (GM-42641) and the Marquette University Committee on Research. We are grateful to the National Science Foundation (CHE-8905465) for partial funding of the purchase of the 300 MHz NMR spectrometer used in this research. High resolution mass spectral determinations were made at the Midwest Center for Mass Spectrometry with partial support by the National Science Foundation, Biology Division (Grant No. DIR9017262). M.J.J. thanks the Korea Science Foundation for support. The authors thank Mr. P.T. Bell for obtaining the $^{13}C$ NMR spectra for **5b** and **11b**, Prof. M. Semmelhack for spectral data for **5a**, and Dr. T.H. Jones for the $^1H$ and $^{13}C$ NMR spectra of **14a/b**.

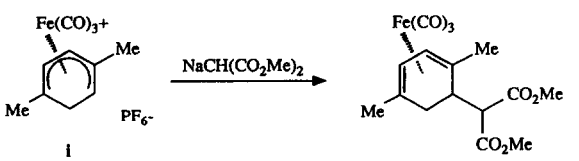
## REFERENCES AND NOTES

1. Davies, S.G.; Green, M.L.H.; Mingos, D.M.P. *Tetrahedron* **1978**, *34* 3047-77; Davies, S.G. "Organotransition Metal Chemistry: Applications to Organic Synthesis", Pergamon Press, New York, NY, 1982; Harrington, P.J. "Transition Metals in Total Synthesis", John Wiley & Sons, New York, NY, 1990.

2. (a) Birch, A J ; Pearson, A.J. *J. Chem. Soc., Perkin Trans. I* **1976**, 954-7; (b) Bonner, T.G.; Holder, K.A.; Powell, P. *J. Organomet. Chem.* **1974**, *77*, C37-C39; (c) Uemura, M; Minami, T.; Yamashita,

Y. *Tetrahedron Lett.* **1987**, *28*, 641-4; (d) Donaldson, W.A.; Ramaswamy, M. *Tetrahedron Lett.* **1988**, *29*, 1343-6; (e) Donaldson, W.A.; Ramaswamy, M. *Tetrahedron Lett.* **1989**, *30*, 1339-42; (f) Donaldson, W.A.; Ramaswamy, M. *Tetrahedron Lett.* **1989**, *30*, 1343-4; (g) McDaniel, K.F.; Kracker, L.R., II; Thamburaj, P.K. *Tetrahedron Lett.* **1990**, *31*, 2373-6; (h) Donaldson, W.A. *J. Organomet. Chem.* **1990**, *395*, 187-93; (i) Yeh, M.-C.P.; Sun, M.-L.; Lin, S.-K. *Tetrahedron Lett.* **1991**, *32*, 113-6; (j) Stephenson, G.R.; Voyle, M.; Williams, S. *Tetrahedron Lett.* **1991**, *32*, 5265-8.

3. a) Pearson, A.J.; Ray, T. *Tetrahedron* **1985**, *41*, 5765-70; b) Semmelhack, M.F.; Park, J. *J. Am. Chem. Soc.* **1987**, *109*, 935-6.
4. Donaldson, W.A.; Jin, M.-J.; Bell, P.T. *Organometallics* **1993**, *12*, 1174-9.
5. The synthesis and reactivity of (4-heterosubstituted-1-methylpentadienyl)iron cations has been reported: a) Donaldson, W.A.; Bell, P.T.; Jin, M.-J. *J. Organomet. Chem.* **1992**, *441*, 449-56; Donaldson, W.A.; Jin, M.-J. *Bull. Soc. Chim. Belg.* **1993**, *102*, 297-8.
6. All compounds are racemic mixtures of enantiomers. Only one enantiomer has been diagrammed for clarity.
7. Semmelhack, M.F.; Bodurow, C.M.; Fewkes, E.; Herndon, J.W.; Knaus, G.; Le, H.T.M.; Sanner, M. *Chem. Scripta* **1985**, *25*, 131-7; Fewkes, E.J., Jr. *Ph.D. Thesis*, Princeton University, 1987.
8. Franck-Neumann, M.; Briswalter, C.; Chemla, P. Martina, D. *Synlett* **1990**, 637-40; Briswalter, C., *Docteur These*, L'Universite Louis Pasteur de Strasbourg, 1991.
9. Moll, V.M.; Behrens, H.; Popp, W. *Z. Anorg. Allg. Chem.* **1979**, *458*, 202-10.
10. Whitesides, T.H.; Neilan, J.P. *J. Am. Chem. Soc.* **1976**, *98*, 63-73.
11. It is of interest to note that (1,4-dimethyl*cyclohexadienyl*)$Fe(CO)_3(1+)$ (**i**), which has a substituent pattern similar to **3b**, reacts with malonate anion via attack only at the less substituted dienyl terminus: Stephenson, G.R. *Aust. J. Chem.* **1982**, *35*, 1939-43.




i

12. Pearson, A.J.; Burello, M.P. *Organometallics* **1992**, *11*, 448-56.
13. The lowest energy conformer of **3b** predicted by molecular mechanics calculations (MMX™, Serena Software) has an Ar-C1 dihedral angle of 65°, while the lowest energy conformer of **1b** has an Ar-C1 dihedral angle of 21°.
14. Hirsch, J.A. "Concepts in Theoretical Organic Chemistry", Allyn and Bacon, Inc., Boston, MA, 1974, p. 95; Ingold, C.K. "Structure and Mechanism in Organic Chemistry", Cornell University Press, Ithaca, NY, 1953, p. 70-71.
15. Lloyd, H.A.; Jones, T.H.; Hefetz, A.; Tengö, J. *Tetrahedron Lett.* **1990**, *31*, 5559-62.
16. Franck-Neumann, M.; Martina, D.; Brion, F. *Angew. Chem. Int. Ed. Engl.* **1978**, *17*, 690-1.
17. McMurry, J. *Org. React.* **1976**, *24*, 187-224.