crystallographic study by Matthews et al.[8] of the ternary complex that *Lactobacillus casei* dihydrofolate reductase (DHFR) forms with NADPH and methotrexate (MTX) indicates that the tetrahydrofolic acid produced by DHFR would have the unnatural *R* configuration at C-6, if dihydrofolic acid (DHF) binds to the enzyme in the same orientation found for MTX. However, these authors have suggested that MTX and DHF might bind to the enzyme in different orientations, with the pteridine rings rotated 180° relative to each other; this alternative orientation would lead to the *S* configuration at atom C-6 of THF, as required by our results.

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Juan C. Fontecilla-Camps,* Charles E. Bugg
Comprehensive Cancer Center
Institute of Dental Research and
Department of Microbiology
University of Alabama in Birmingham
Birmingham, Alabama 35294

Carroll Temple, Jr., Jerry D. Rose
John A. Montgomery
Department of Organic Chemistry Research
Kettering-Meyer Laboratory
Southern Research Institute
Birmingham, Alabama 35205

Roy L. Kisliuk
Department of Biochemistry and Pharmacology
Tufts University, School of Medicine
Boston, Massachusetts 02111

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Pentacarbonyl(7-η^1-cycloheptatrienyl)rhenium. Synthesis and Fluxional Behavior of a *Monohapto*cycloheptatrienyl Derivative of a Transition Metal

Sir:

Although the η^3, η^5, and η^7 bonding modes of the cycloheptatrienyl ligand are well established, no *monohapto*-7-cycloheptatrienyl derivative of a transition metal is known.[1] The lack of such compounds is noteworthy, since they would provide the simplest cyclic system in which a 1,5 sigmatropic shift (as expected from orbital symmetry rules[2] for "ordinary" migrating groups) could be distinguished from the 1,2 (least motion) pathway. For the intensively studied η^1-C_5H_5 derivatives,[3] these pathways are of course not distinguishable. We now report the synthesis of (7-η^1-C_7H_7)Re(CO)$_5$, the first *monohapto*-7-cycloheptatrienyl derivative of a transition metal, and a study of its fluxional character which establishes a 1,2 shift as the only observable migration pathway.

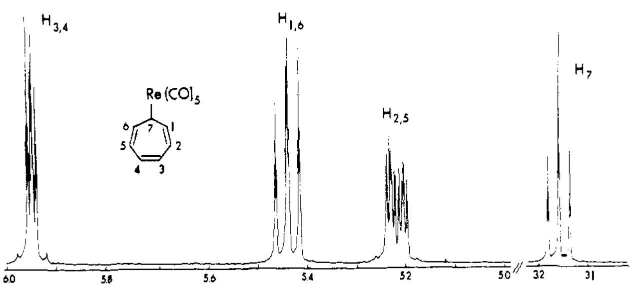
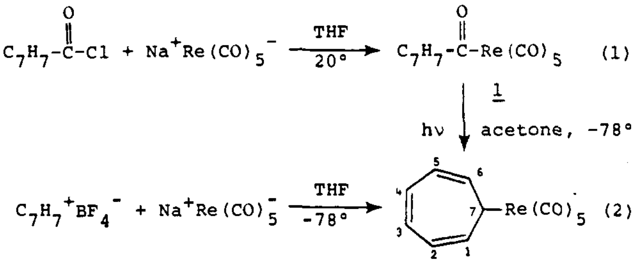


Figure 1. 400-MHz ^{1}H NMR spectrum of (7-η^1-C_7H_7)Re(CO)$_5$ (**2**) in methylcyclohexane-d_{14} at 30 °C. Scale is in parts per million from Me_4Si = 0. Precise chemical shifts and assignments are given in note 7. Irradiation at δ 3.16 ppm causes an intensity decrease in the signal at δ 5.44 ppm.

The title compound has been prepared in two ways. In the first (eq 1), addition of 7-cycloheptatrienylacyl chloride[4] to a tetrahydrofuran (THF) solution of $Na^+Re(CO)_5^-$ affords the acyl **1**.[5] Decarbonylation of **1** under ultraviolet light[6] affords the 7-η^1-cycloheptatrienyl derivative **2** as orange, air-stable needles.[7,8] In the second method (eq 2) reaction of tropylium cation with $Na^+Re(CO)_5^-$ affords **2** in 90% yield; this facile reaction is surprising in view of earlier reports of carbonyl anion-tropylium cation reactions in which metal carbonyl dimers and ditropyl are formed,[10] or one instance where a trihapto derivative was formed in low yield.[11] We attribute the difference to the strength of rhenium-carbon bonds.[12]



2

The fluxional behavior of **2** was studied using the spin saturation transfer technique[13] in dioxane-d_8.[14] Irradiation of H_7 (see Figure 1) in the 25–37° range caused the $H_{1,6}$ resonance to decrease in intensity[15] while the other olefinic resonances were unaffected. This result is a clear, qualitative indication that H_7 is exchanging with $H_{1,6}$ but not with $H_{2,5}$ or $H_{3,4}$, i.e., that a 1,2 shift is taking place.[16] Quantitative results are summarized in Table I, from which activation parameters[17] for the 1,2 shift in **2** are as follows: $\Delta G^{\ddagger}_{300} = 19.8 \pm 0.1$ kcal mol^{-1}, $\Delta H^{\ddagger} = 18.1 \pm 1.9$ kcal mol^{-1}, $\Delta S^{\ddagger} = -5.7 \pm 2$ eu.[18]

It is of interest to compare the 1,2 or least motion shift established here for **2** with the 1,5 shift observed[19] and recently confirmed[20] in (7-η^1-C_7H_7)Sn(C_6H_5)$_3$ (**3**), for which $\Delta G^{\ddagger}_{300} = 15.44 \pm 0.14$ kcal mol^{-1}.[20] Migration in the tin derivative conforms to the ordinary symmetry rules, while in the transition metal derivative it does not. It has occasionally been suggested[20,21] that orbital symmetry restrictions might be relaxed when the migrating group possesses valence-shell d orbitals; the present case provides the first test of this possi-

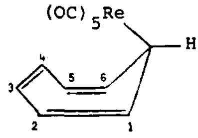
Table I. Spin Saturation Transfer Data for **2**[a]

T, K	T_1 of $H_{1,6}$[b]	$\frac{M_z(0) - M_z(\infty)}{M_z(\infty)}$[c]	$k \times 10^2$, s^{-1} [d]
298	6.47	0.11	1.70
301	6.87	0.19	2.77
304	7.27	0.23	3.16
307	7.67	0.38	4.95
310	8.07	0.47	5.83

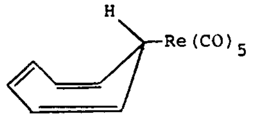
[a] In dioxane-d_8 solvent. [b] Measured using a π, τ, $\pi/2$, $5T_1$ sequence. [c] $M_z(0)$ is the normal equilibrium magnetization of $H_{1,6}$ and $M_z(\infty)$ is the equilibrium magnetization of $H_{1,6}$ with saturation of H_7. [d] The rate constant, k, for exchange in a two-site equal population system is given by $k = 1/T_{1(1,6)}[(M_z(0) - M_z(\infty)/M_z(\infty)]$.[23] The two-site treatment is adequate since the rate of 1,3 and 1,4 shifts is zero in the temperature range studied.

bility. The result demonstrates for the first time a clear difference between main and transition group systematics, posing an interesting problem for the theory of sigmatropic shifts.

Two conformations are possible for **2**, which may have the $Re(CO)_5$ moiety in a quasi-axial (**2a**) or quasi-equatorial (**2b**) position. The observed H_1–H_7 coupling constant in **2** is 8.7 Hz, similar to the value of 8 Hz observed for the triphenyltin derivative **3**;[20] **3** has been shown by X-ray crystallography to have the substituent in the quasi-axial position.[22] If it is the case that **2a** is the predominant or only conformer present in solutions of **2**, there should be no geometric constraint on a 1,5 shift, and the different migration pathways of the rhenium and tin compounds must be otherwise explained.



2a



2b

We are continuing this investigation on the assumption that other stable *monohapto*-7-cycloheptatrienyl derivatives of transition metals can be synthesized and that their study will contribute to the understanding of fluxional processes in organometallic chemistry.

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(5) Compound **1** was isolated in 70% yield as pale yellow crystals: mp 98 °C; IR (cyclohexane, ν_{CO} with assignment, cm^{-1}) 2132 (w, A_1), 2061 (w, B_1), 2023 (s, E), 2014 (s, E), 1999 (s, A_1), 1637, 1626 (w, acyl CO); ^1H NMR (methylcyclohexane-d_{14}, δ) 6.51 (m, $H_{3,4}$), 6.18 (m, $H_{2,5}$), 5.12 (m, $H_{1,6}$), 2.50 (t, H_7) ($^3J_{17}$ = 5.8 Hz). Anal. Calcd for $C_{13}H_7O_6Re$: C, 35.04; H, 1.57. Found: C, 35.08; H, 1.70.

(6) Hanovia 140-W lamp, quartz vessel, acetone, −78 °C.

(7) The yield of **2** in decarbonylation step was 60%: mp 74 °C; IR (cyclohexane, ν_{CO}, cm^{-1}) 2120 (w), 2015 (s), 1983 (m); mass spectrum, molecular ion of correct isotope pattern at *m/e* 418; ^{13}C NMR (0 °C, methylcyclohexane-d_{14}, 22.6 MHz, δ) 17.71 (C_7), 122.09 ($C_{2,5}$), 135.73 ($C_{3,4}$), 140.14 ($C_{1,6}$), 181.1 (axial ReCO), 187.0 (equatorial ReCO) (olefinic ^{13}C assignments by selective proton decoupling); ^1H NMR (30 °C, methylcyclohexane-d_{14}, 400 MHz, δ) 3.16 (tt, H_7), 5.24 (m, $H_{2,5}$), 5.44 (m, $H_{1,6}$), 5.96 (m, $H_{3,4}$) ($^3J_{17}$ = 8.7, $^4J_{27}$ = 1.0, $^3J_{12}$ = 10.1 Hz). Anal. Calcd for $C_{12}H_7O_5Re$: C, 34.52; H, 1.69. Found: C, 34.54; H, 1.78.

(8) The manganese analogue of **1** is known, but only (η^5-C_7H_7)$Mn(CO)_3$ was isolated after low temperature irradiation.[9]

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(13) For a readable account of this method, cf. J. W. Faller in "Determination of Organic Structures by Physical Methods", Vol. 5, F. C. Nachod and J. J. Zuckerman, Eds., Academic Press, New York, 1973, Chapter 2.

(14) Dioxane was used in the quantitative experiments because the stability of **2** was somewhat greater in this solvent than in methylcyclohexane. Qualitative conclusions from spin saturation transfer experiments are the same in both solvents. Some line broadening was observed at 70 °C in methylcyclohexane, but the migration pathway could not be studied by this method as decomposition was too rapid at this temperature.

(15) Saturation of H_7 at 15 °C results in no nuclear Overhauser enhancement of the $H_{1,6}$ signal.

(16) The same conclusion was reached from ^{13}C NMR studies, in which irradiation at δ 17.71 diminished the peak at 140.14 but not the others. Quantitative treatment of the ^{13}C data is complicated by the widely different relaxation times of C_7 (1.4 s) and $C_{1,6}$ (2.7 s).

(17) The error limits quoted are standard deviations of the least-squares straight line in the Eyring plot and consequently give only minimum errors.

(18) This small negative entropy of activation is not consistent with a dissociative process. Preliminary studies of the kinetics of thermal decomposition of **2** (in which cycloheptatriene, ditropyl, and $Re_2(CO)_{10}$ are formed) in dioxane led to $\Delta G^{\ddagger} \simeq 25$ kcal mol^{-1} at 42 °C. This value must represent a minimum activation energy for homolysis to $\cdot Re(CO)_5$ and $\cdot C_7H_7$ fragments; so we conclude that such bond breaking is not significant in the observed migration.

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D. Michael Heinekey, William A. G. Graham*
Department of Chemistry, University of Alberta
Edmonton, Alberta, Canada T6G 2G2

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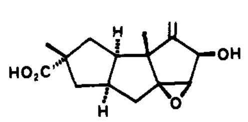
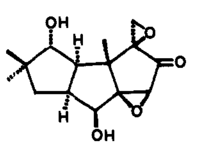
A New, Stereocontrolled Synthesis of *cis,anti,cis*-Tricyclo[6.3.0.0^{2,6}]undecanes. Total Synthesis of (±)-Hirsutene

Sir:

The *cis,anti,cis*-tricyclo[6.3.0.0^{2,6}]undecane system is found in the carbon skeleton of the hirsutane group of sesquiterpenes, as for example, hirsutic acid[1] (**1**), coriolin[2] (**2**), and their biogenetic precursor, hirsutene[3] (**3**). These substances are known to be endowed with remarkable biological properties and have been the subject of intense synthetic investigation, recently culminating in the description of the biogenetic-like synthesis of hirsutene[4] and a stereocontrolled synthesis of hirsutic acid.[5]



1



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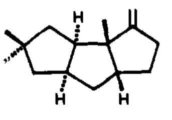

3

We report herein a new stereocontrolled synthesis of hirsutene and the chemical precursors of coriolin and thus record a general method of entry into the *cis,anti,cis*-tricyclo[6.3.0.0^{2,6}]undecane series. The key step in this approach is a unique skeletal rearrangement of a tricyclic 6-4-5-fused ring to a cis,anti,cis-tricyclic 5-5-5-fused ring. The cis,syn,-cis-tricyclic series, the stereochemistry of which is incompatible with that of the hirsutane skeleton, have been synthesized by photocycloaddition.[6]