

in the result, densities may be determined for much larger systems of chemical interest.

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References and Notes

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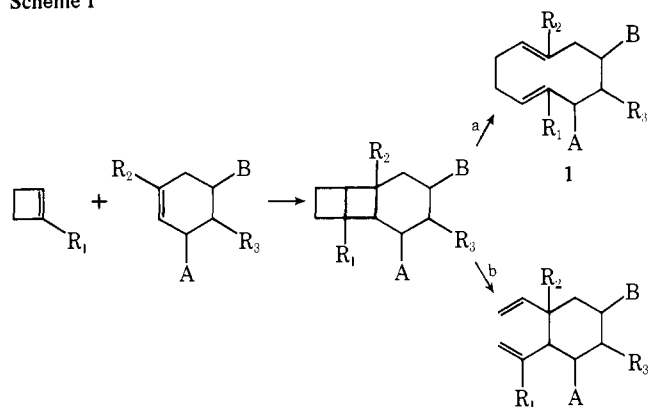
Methods for the Preparation of 1,5-Dienes. A Metathetical Route to Medium-Sized Carbocycles

Sir:

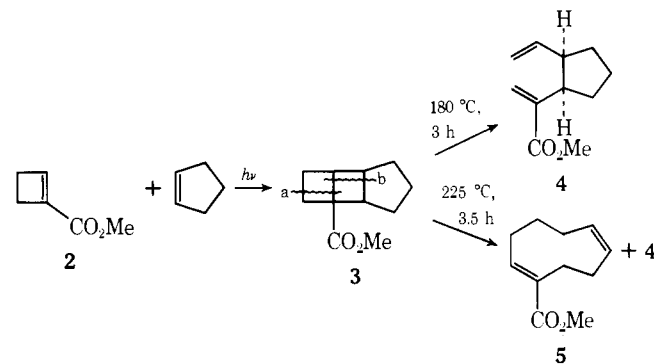
The development of methods for the synthesis of medium-sized carbocycles is stimulated by the occurrence of such moieties in multifarious natural products of biological interest. Important synthetic targets among such naturally occurring carbocycles include the germacradienes,¹ a sesquiterpene family characterized by a ten-membered ring nucleus **1**. Interest in the synthesis of compounds of this structural type arises, in part, from the reported *in vivo* activity² of various germacradienes against carcinosarcoma in rats and lymphocytic leukemia in mice and their further use in biogenetically modeled syntheses of other sesquiterpene skeletons.³ In connection with these considerations, we wish to report the synthetic salience of a metathetical route (a) to medium-sized carbocycles following the strategy outlined in Scheme I. A variation (b) of this merged cycloaddition–retrocycloaddition sequence is also described which allows for the addition of differentiated vinyl groups across a carbon–carbon double bond.

The previously unreported photocycloaddition of methyl cyclobutenecarboxylate (**2**)⁴ with cycloalkenes provided a convenient route to the tricyclic intermediates in the above sequence. For example, irradiation⁵ (3 h) of a 0 °C degassed methylene chloride solution of ester **2** and cyclopentene afforded photoadduct **3**⁶ (67% yield; IR (neat) 1725 cm⁻¹; NMR (CDCl₃) δ 3.66 (s, 3), 1.47–3.08 (m, 13)), which was initially used to evaluate the above strategy. When photoadduct **3** (0.2 M benzene, sealed Pyrex tube) was heated at 180 °C for 3 h, ester **4** was obtained in 70% yield along with unreacted starting material. The structure of **4** is indicated by its spectroscopic properties (IR (neat) 1730 cm⁻¹; NMR (CDCl₃) δ 6.17 (bs, 1), 4.69–5.70 (m, 3), 5.44 (bs, 1), 3.69 (s, 3), 2.72–3.23 (m, 2), and 1.33–2.22 (m, 6)) and conversion (O₃, HOAc/EtOAc, 0 °C; H₂O₂, 65 °C, 12 h) to *cis*-1,2-cyclopentenedicarboxylic acid (mp 135–136 °C).⁷ The formation of ester **4**, in this in-

Scheme I

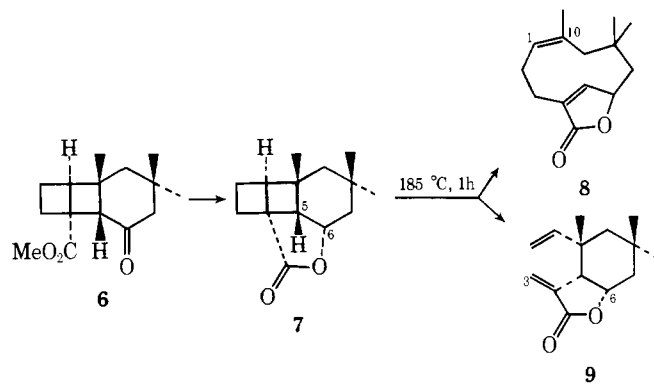


stance, may be explained by kinetic cleavage (a) of photoadduct **3** or cleavage (b) followed by a Cope rearrangement.⁸



That the course of the above rearrangement and, hence, product formation can be subject to experimental control was demonstrated in a second pyrolysis experiment using photoadduct **3** (0.2 M benzene, 225 °C, 3.5 h). Under these conditions, cyclononadiene ester **5** and ester **4** (2:1 mixture) were obtained in a combined yield of 90%. The structure of **5** is assigned from its spectroscopic data (IR (neat) 1710 and 730 cm⁻¹; NMR (CDCl₃) δ 6.80 (t, 1, $J = 9$ Hz), 5.77 (dt, 1, $J = 8$ and 10.5 Hz), 5.42 (dt, 1, $J = 8$ and 10.5 Hz), 3.72 (s, 3), and 1.44–2.50 (m, 10)), conversion to cyclononancarboxylic acid^{9a} (anilide, mp 140–141 °C),^{9b} and interconversion with ester **4**.⁸ Since the same ratio of esters (**5/4** = 2/1) is obtained when ester **4** is subjected to the above pyrolysis conditions, product formation, in this case, is thermodynamically controlled.

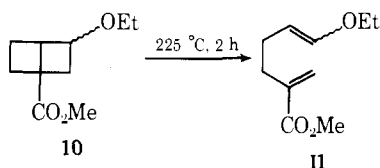
This approach is readily extended to the cyclodecadiene system. Thus, irradiation (Pyrex filter)^{5,10} of a 0 °C degassed methylene chloride solution of isophorone and ester **2** afforded ketoester **6** (85% yield based on ester **2**). The isomeric purity of this product is indicated by its homogeneity by thin-layer chromatography and the presence of only four methyl singlets in its NMR spectrum (partial NMR (CDCl₃) δ 3.54 (s, 3), 1.29 (s, 3), 1.01 (s, 3), 0.94 (s, 3)) and corresponding



$\text{Eu}(\text{C}_{11}\text{H}_{19}\text{O}_2)_3$ -shifted NMR spectrum. The *cis-anti-cis*, head-to-head structure for ketoester **6** is based on its conversion (NaBH_4 , ethanol; 1 N HCl, 45 min) to crystalline lactone **7** [65% yield; IR (CCl_4) 1760 cm^{-1} ; NMR (CDCl_3) δ 4.82 (C-6 hydrogen, dt, $J = 5$ and 9.5 Hz), 1.15–2.95 (multiplet with C-5 hydrogen as doublet ($J = 9.5$ Hz) at δ 2.62, 10), 1.30 (s, 3), 1.01 (s, 3), and 0.92 (s, 3)]¹¹ and recovery after prolonged exposure (5 h) to alumina.¹²

Pyrolysis of lactone **7** (0.3 M benzene, 185 °C, 1 h) afforded cyclodecadiene lactone **8** and methylene lactone **9** in a ratio of 2:1. This ratio of lactones **8** and **9** reflects the products of kinetic cleavage of lactone **7** since subsection of either **8** or **9** to the above pyrolysis conditions showed no sign of equilibration and heating either **8** or **9** (0.3 M benzene, sealed Pyrex tube) at 240 °C for 12 h provided the equilibrium mixture, $\mathbf{8/9} = 1/2$. The structure of cyclodecadiene lactone **8** is assigned from its spectroscopic properties (IR (CCl_4) 1750 cm^{-1} ; NMR (CDCl_3) δ 6.62 (bs, 1), 5.18 (m, 1), 5.03 (m, 1), 1.38–2.92 (m, 8), 1.84 (s, 3), 1.13 (s, 3), and 1.10 (s, 3)) including an observed NOE effect (11%) between the C-1 hydrogen and C-10 methyl signals.¹³ The structure of methylene lactone **9** follows from its spectroscopic data (IR (CCl_4) 1770 cm^{-1} ; NMR (CCl_4) δ 6.20 (C-3 hydrogen, bs), 5.57 (C-3 hydrogen, bs), 4.40–6.10 (vinyl ABX overlapping with C-6 hydrogen multiplet, 4), 2.80 (m, 1), 1.18–2.50 (m, 4), 1.14 (s, 3), 1.06 (s, 3), and 1.02 (s, 3)) and interconversion with **8**.⁸ The formation of lactones **8** and **9** from the rearrangement of lactone **7** is consistent with orbital symmetry predictions¹⁴ and parallels the related transformations of bicyclo[2.2.0]hexanes¹⁵ and dihydrophotoisabelin.¹⁶

The above metathetical strategy can also be extended to the preparation of acyclic 1,5-dienes as indicated by the exclusive formation of ester **11** upon rearrangement (225 °C, 2 h) of photoadduct **10**.¹⁷



The method reported above provides a convenient route to cyclic and acyclic 1,5-dienes which is readily performed on a preparative scale. Furthermore, the metathetical strategy offers several important features, which bear on its application to germacradiene synthesis, including a convergent, highly regioselective route to the ten-membered ring and the capability of transferring stereochemistry and functionality from a readily elaborated small ring precursor to the target carbocycle. Further studies are in progress.

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Anomalous Large Long-Range Halogen Hyperfine Coupling in 4-Halo-1-norbornyl Radicals

Sir:

A good deal of experimental and theoretical work has been devoted to studies of long-range proton hyperfine splitting constants (hfsc) over three or more σ -bonds.¹ In contrast, very few investigations of long-range hfsc involving halogen atoms have been reported. It seemed worthwhile to investigate the magnitude of long-range halogen coupling by electron paramagnetic resonance spectroscopy (EPR) since it has been suggested that halogen substituents located three or more bonds removed from the radical center may influence both the stereochemistry and kinetics of various homolytic processes.^{2–4} The rigid structure of the 1-norbornyl radical⁵ makes this system an ideal substrate for studies of long-range interactions of this type. In this communication we wish to report the results of our preliminary EPR investigation of long-range coupling in 4-halo-1-norbornyl radicals.

As suggested by the reported photobehavior of 1-iodonorbornane,⁶ it proved possible to prepare the necessary 1-norbornyl radicals (**4**, **5**, **6**) from suitably substituted 1-iodonorbornanes⁷ (**1**, **2**, **3**) by irradiation of a dilute mixture of the appropriate iodide in argon at 12 K with a filtered (Cs-7-54) mercury resonance lamp.⁸

Photolysis of a dilute mixture of **1** in argon at 12 K gave the EPR spectrum shown in Figure 1A. This 1:2:1 pattern results from the two exo β -protons of the 1-norbornyl radical (**4**) as has been shown by Kawamura et al.⁵ for this radical in solution. Although these β -proton hfsc are small (9.81 G in solution) due to their orientation with respect to the unpaired electron orbital and to the strained geometry at the radical site,⁵ they

