Although it might be argued that an illustration from radical chemistry is of doubtful relevance here, the transition states calculated by ab initio methods for hydride addition to acetylene[15] and for hydrogen atom addition to acetylene[17] are remarkably similar.

An example[18] which has been cited[2] of a 4-endo-dig reaction, the ready occurrence of which seems unreasonable on the present argument, notwithstanding the predicted[15] bending of the acetylene at the transition state for nucleophilic addition, may well involve a larger ring transition state incorporating a molecule of water.

Acknowledgment. We are indebted to Professor R. F. Hudson, Dr. D. Griller, and Dr. M. C. Grossel for helpful comments. M.J.P. also thanks NATO for a travel grant, during the tenure of which in 1978 he gave a seminar at NRCC which led to the present work, as well as Dr. K. U. Ingold for his hospitality at NRCC.

Registry No. 2, 115-07-1; **3**, 41879-84-9; **8**, 78-85-3; **9**, 71298-09-4.

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[16] Warkentin, J.; Ingold, K. U. *Can. J. Chem.* **1980**, *58*, 348.

[17] Nagase, S.; Kern, C. W. *J. Am. Chem. Soc.* **1979**, *101*, 2544.

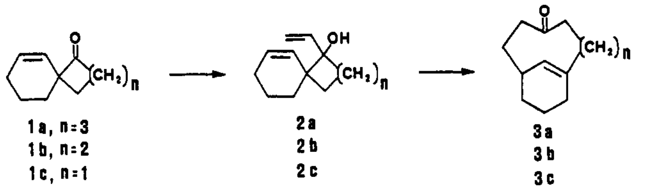
[18] Hekkert, G. L.; Drenth, W. *Recl. Trav. Chim. Pays-Bas* **1961**, *80*, 1285.

Communications

Oxy-Cope Rearrangement Route to Bridgehead Olefins[1]

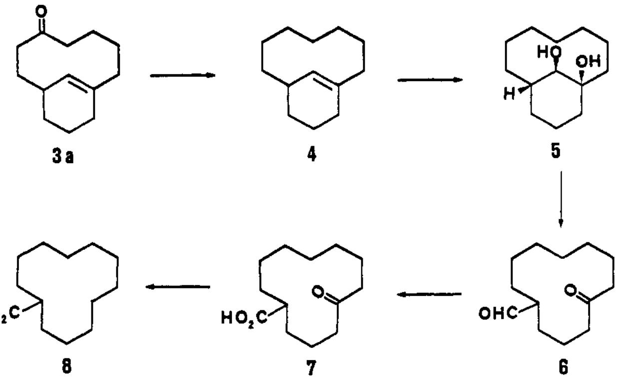
Summary: Bicyclic bridgehead olefins, with a carbonyl group included in the largest bridge, may be synthesized by oxy-Cope rearrangement of easily accessible spirocyclic precursors.

Sir: Our interest in the influence of through-space interactions on the reactivity of functional groups[2] has led us to develop a general method for the construction of bicyclic bridgehead olefins in which a carbonyl group is included in the largest bridge. This method is based on the anionic oxy-Cope rearrangement[3] of vinyl carbinols of type **2** to the δ,ϵ-unsaturated ketones **3**.



The vinyl carbinol **2a**,[4] obtained by vinylmagnesium bromide addition to the spiroannulated cyclohexanone **1a**,[4,5] was converted (KH in THF) to the potassium salt and then heated under reflux for 4 h. Normal workup and purification by distillation gave the unsaturated ketone **3a** in 79% yield. The structure of ketone **3a**[7] was verified by the degradation sequence given in Scheme I. Wolf–Kishner reduction to **4** followed by osmium tetroxide oxidation gave diol **5**,[4] mp 109–109.5 °C, which was oxidized ($Pb(OAc)_4$ followed by Jones oxidation) to keto acid **7**,[4] mp 126.5–127.5 °C. A second Wolf–Kishner reduction then provided the known cyclododecanecarboxylic acid **8**,[4] mp 93.5–95.0 °C (lit.[8] mp 93–95 °C). Bridgehead olefin **4** was also subjected to hydroboration–oxidation; the major product (65%) was a secondary alcohol, mp 133.0–135.5 °C, whose ^{13}C NMR spectrum revealed only eight different carbon resonances as expected for the symmetrical structure **9**.[4,9]

Scheme I



The vinyl carbinol **2b**,[4] derived from spiroannulated cyclopentanone **1b**,[6] when subjected, as above, to the anionic oxy-Cope rearrangement conditions provided oxocycloalkene **3b**[10] in 83% yield.

The vinyl carbinol **2c** (from cyclobutanone **1c**[11]), as the potassium salt, was found to undergo rearrangement in THF solution at an appreciable rate at room temperature. After 12 h, normal workup and purification by chromatography on silica gel gave the unstable oxocycloalkene **3c**[12,13] in 47% yield. Catalytic hydrogenation of **3c** afforded

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[1] Presented in part at the 1980 American Chemical Society Combined Southeast–Southwest Regional Meeting, New Orleans, LA, Dec 10–13, 1980.

[2] S. G. Levine, R.-C.L. Hsu, and M. L. Miles, *Tetrahedron Lett.*, 3347 (1980).

[3] D. A. Evans and A. M. Golob, *J. Am. Chem. Soc.*, **97**, 4765 (1975).

[4] A satisfactory elemental analysis was obtained for this product.

[5] Ketone **1a** was prepared from methyl cyclohex-2-enecarboxylate by alkylation with ethyl 5-bromopentanoate, Dieckmann cyclization, and decarboethoxylation. These reactions were carried out essentially as described[6] for the five-membered ketone **1b**.

[6] E. J. Corey, M. Petrzilka, and Y. Ueda, *Tetrahedron Lett.*, 4343 (1975); *Helv. Chim. Acta*, **60**, 2294 (1977).

[7] IR (CS_2) 3005, 1697 cm^{-1}; ^1H NMR ($CDCl_3$ δ 5.10 (s, 1 H); ^{13}C NMR ($CDCl_3$) 213.3, 138.6, 128.2, 44.4, 37.7, 37.4, 35.6, 34.0, 29.4, 28.1, 25.7, 23.1, 22.3 ppm; mass spectrum (70 eV), *m/e* 192 (14%), 174 (100%), 131 (26%), 120 (45%), 91 (80%), 79 (100%).

[8] A. P. Krapcho and R. G. Johanson, *J. Org. Chem.*, **36**, 146 (1971).

[9] The slightly more polar diastereomeric secondary alcohol was also isolated (7% yield) and gave 13 signals in its ^{13}C NMR spectrum.

[10] IR ($CHCl_3$) 3020, 1695 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.10–2.60 (m, 17 H), 5.40 (d, $J = 5$ Hz, 1 H); ^{13}C NMR ($CDCl_3$) 213.8, 140.6, 129.2, 43.7, 41.3, 36.4, 34.3, 30.0, 27.9, 27.6, 26.6, 17.7; mass spectrum (70 eV), *m/e* 178 (5%), 160 (100%).

[11] B. M. Trost, D. E. Keeley, H. C. Arndt, J. H. Rigby, and M. J. Bogdanowicz, *J. Am. Chem. Soc.*, **99**, 3080 (1977).

[12] IR (CS_2) 1695 cm^{-1}; ^1H NMR ($CDCl_3$) 1.00–3.20 (m, 15 H), 5.20 (br s, 1 H); mass spectrum, *m/e* 164 (64%), 79 (100%); ^{13}C NMR ($CDCl_3$) 217.4, 142.2, 128.8, 48.2, 38.7, 38.2, 36.4, 33.8, 29.6, 25.8, 21.6 ppm.

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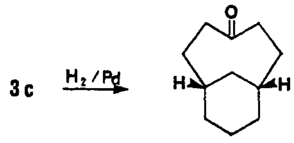
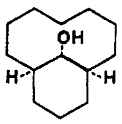
the saturated ketone **10**[14] (semicarbazone,[4] mp 187–188 °C) whose symmetry is revealed by its seven-line ^{13}C NMR spectrum.



10



9

Several aspects of the chemistry of the bridgehead olefins **3a–c** are under investigation.[15]

Registry No. 1a, 77080-00-3; **1b**, 65173-72-0; **1c**, 41597-04-0; **2a**, 77080-01-4; **2a**·K, 77080-02-5; **2b**, 77080-03-6; **2c**·K, 77080-04-7; **3a**, 77080-05-8; **3b**, 77080-06-9; **3c**, 77080-07-0; **4**, 77080-08-1; **5**, 77080-09-2; **7**, 77080-10-5; **8**, 884-36-6; **9**, 77080-11-6; **10**, 77080-12-7; **10** semicarbazone, 77080-13-8; vinyl bromide, 593-60-2; methyl cyclohex-2-enecarboxylate, 25662-37-7; ethyl 5-bromopentanoate, 14660-52-7.

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[13] The anionic oxy-Cope rearrangement of **2c** to **3c** has very recently been carried out as a model reaction for the key step in a prospective synthesis of the antibiotic pleuromutilin. M. Kahn, *Tetrahedron Lett.*, 4547 (1980).

[14] IR (CS_2) 1690 cm^{-1}; ^{13}C NMR ($CDCl_3$) 215.4, 43.0, 31.9, 30.5, 29.6, 28.8, 16.6 ppm; mass spectrum (70 eV), *m/e* 166 (66%), 67 (100%).

[15] A comprehensive review by Kenneth J. Shea of recent developments in the synthesis, structure, and chemistry of bridgehead olefins is scheduled for publication in *Tetrahedron*. We thank Professor Shea for sending us a prepublication copy of his manuscript.

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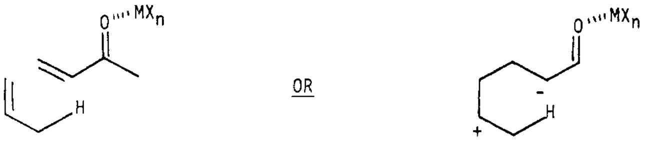
Received December 23, 1980

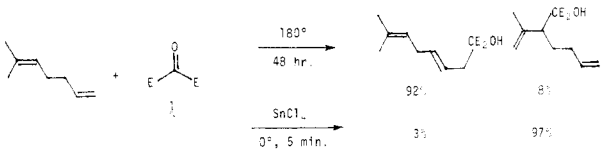
Changes in Ene Reaction Mechanisms with Lewis Acid Catalysis

Summary: Inter- and intramolecular isotope effects for both thermal and $SnCl_4$-catalyzed ene reactions of oxomalonic esters have been measured. Primary isotope effects are high (~3.3) in thermal reactions and negligible (~1.1) in $SnCl_4$-catalyzed cases, even where intramolecular competitions are available. A concerted mechanism with variations in C–C bond formation and C–H(D) bond breaking is proposed. A potentially useful cyclization reaction is also described.

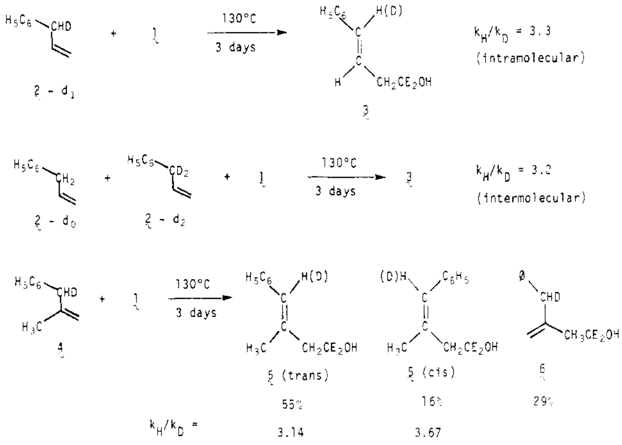
Sir: Interest in synthetic applications of the ene reaction has increased substantially with the demonstrations by several groups that Lewis acid catalysis can be dramatic. In many cases, additions of less than molar amounts of aluminum or tin halides have made it possible to reduce reaction times and temperatures to points where conditions are quite mild.[1] In a recent review, Snider[1] has summarized evidence related to the two limiting mechanisms in these catalyzed cases, namely, the concerted and dipolar pathways. This present study compares deuterium isotope effects for thermal and tin chloride catalyzed ene reactions of dimethyl and diethyl oxomalonates **1**. We conclude, even in this extreme case, that dipolar intermediates are not fully formed.



Salomon and co-workers[2] have reported that diethyl oxomalonate (**1**, E = carboethoxy or carbomethoxy) undergoes clean ene reactions both thermally and with $SnCl_4$ catalysis. It is obvious from the example given below that the $SnCl_4$ catalysis is profound and that the reactive species in the catalytic reaction is very much more electrophilic than is oxomalonate alone. Regiospecificity changes such as that shown are consistent with this increase in electrophilicity.



Isotope effect measurements suggest that the uncatalyzed ene reaction of oxomalonate is unremarkable. Both intra- and intermolecular isotope effects are high. These high, primary isotope effects are consistent with those found in a variety of other concerted ene fractions.[3] Even without a detailed stereochemical study, we are confident that this represents a one-step ene reaction with C–H bond breaking and C–C bond making occurring at about the same time. Recent isotope effect measurements by Achmatowicz and Szymoniak[4] and an accompanying detailed analysis support this point of view.



Catalysis of this reaction with small amounts of $SnCl_4$ results in a substantial reduction in the magnitude of the isotope effect. Both inter- and intramolecular competitions are affected to a very similar degree.

These data suggest that C–H or C–D bond breaking is a much less significant aspect of transition-state structure in catalyzed relative to uncatalyzed cases. The most economical explanation is that a concerted reaction continues to prevail but that C–H(D) bond breaking may have only slightly progressed at the transition state. These data allow a rigorous elimination of a mechanism in which formation of a dipolar intermediate is followed by C–H(D) bond breaking with a significant activation energy. In the

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[1] Snider, B. B. *Acc. Chem. Res.* **1980**, *13*, 426–432.

[2] Salomon, M. F.; Pardo, S. N.; Salomon, R. G. *J. Am. Chem. Soc.* **1980**, *102*, 2473.

[3] Stephenson, L. M.; Mattern, D. L. *J. Org. Chem.* **1976**, *41*, 3614.

[4] Achmatowicz, O., Jr.; Szymoniak, J. *J. Org. Chem.* **1980**, *45*, 1228; *Ibid.* **1980**, *45*, 4774.

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