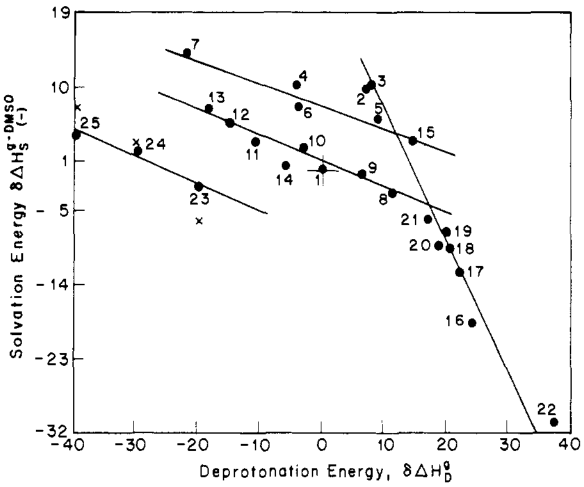
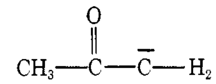


Figure 1. Comparison of gas phase deprotonation enthalpies of protonic acids in Table I, relative to cyclopentadiene, with corresponding solvation enthalpies of their anions in DMSO. Values for halide ions in water (X) estimated from enthalpies of transfer in ref 13.

dency toward solvation by ion–dipole interactions at a specific site. The differentiated solvation energies of N≡C—CH_2^-, *t*-Bu—C≡C^-, and


$CH_3—\overset{\overset{O}{\|}}{C}—\bar{C}—H_2$

are interesting in view of the nearly equal gas phase acidities of their neutrals. The position of the acetonyl anion is especially noteworthy since it links the charge-delocalized enolates with charge-localized alkoxides.

The spherical halide ions, unencumbered with organic groups, provide the normative electrostatic model for the effect of ion solvation. The difference between their behavior in aprotic DMSO and in water[13] is attributed to differences in polarizability and hydrogen bonding. The unusually high solvation enthalpy of cyclopentadienyl anion relative to the other hydrocarbanions is consistent with Bordwell's proposal that dispersion force solvation is important here because of its unique degree of symmetrical charge delocalization over a relatively small volume.

Finally, we emphasize the striking sensitivity of alkoxide ion solvation energies to elaboration of the alkyl group. When contrasted with the other organic ions, their behavior strongly confirms our previous suggestion[4] that steric hindrance to ion solvation is responsible for the dramatic difference between their basicity in the gas phase and that in solution. The possibilities for exploiting this phenomenon have already been noted.[14]

On the recommendation of a referee we wish to point out that the *accuracy* of some of the gas phase data, on which the derived solvation enthalpies depend, is questionable since they have not all been linked together by stepwise equilibration. We have therefore not reported the standard deviations of solvation enthalpies in the last column of Table I since such formal estimates of *precision* could give a misleading impression of their ultimate reliability. However, we have confidence in the basic conclusions expressed here for the following reasons: (a) Taft[15] has found close agreement between Kebarle's high pressure mass spectrometry results and independent icr equilibration studies, (b) the alkoxide values were in fact based on gas phase equilibration,[4] (c) Bordwell[6] has noted systematic agreement between Kebarle's gas phase acidities and pK_a's in DMSO for series of similar carbon acids. His results, like those in Figure 1, suggest that major inaccuracies in the gas phase acidities would probably result in vertical displacement of the parallel lines with respect to each other rather than their slopes.

Acknowledgments. We appreciate the kindness of Professors Kebarle and Bordwell for providing us with valuable unpublished data.

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(11) Evidence that ion-pairing energies between these anions and the potassium counterion are negligible is found in (a) the close correlation of our data with Bordwell's[7a,8] although his anion concentration is a hundredfold[7a] less than ours and (b) the insensitivity of our ΔH_D (DMSO) values for acetylacetone, phenylacetonitrile, and cyclopentadiene to the addition of di-benzo-18-crown-6 ether—a strong complexing agent for potassium ion.[7b]
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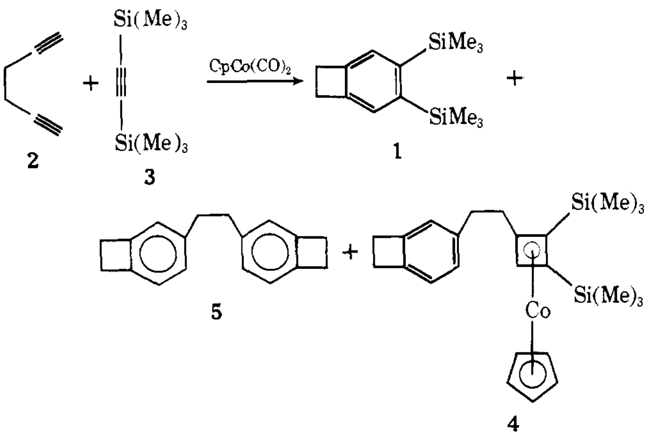
Transition Metal Catalyzed Acetylene Cyclizations. 4,5-Bis(trimethylsilyl)benzocyclobutene, a Highly Strained, Versatile Synthetic Intermediate

Sir:

Benzocyclobutenes, valuable precursors to theoretically interesting molecules,[1] are now gaining increasing importance as intermediates toward the synthesis of natural products.[2,3] For this purpose complete control of substitution in the aromatic ring of benzocyclobutene is highly desirable and has been the source of considerable synthetic difficulty.[4] We have recently developed a general synthesis of benzocyclobutenes via the cooligomerization[5] of 1,5-hexadiynes and substituted acetylenes using a cobalt catalyst.[6] Yields, however, were only moderate (ca. 15%) for functionalized systems, and benzocyclobutenes substituted by electrophilic moieties (halogen, acetyl, etc.) were inaccessible due to the instability of the corresponding acetylenic precursors and/or catalyst under the reaction conditions.[7]

We now wish to report a solution to both of these problems by the synthesis and chemistry of the most strained[8] simple benzocyclobutene hitherto synthesized, 4,5-bis(trimethylsilyl)benzocyclobutene (**1**).

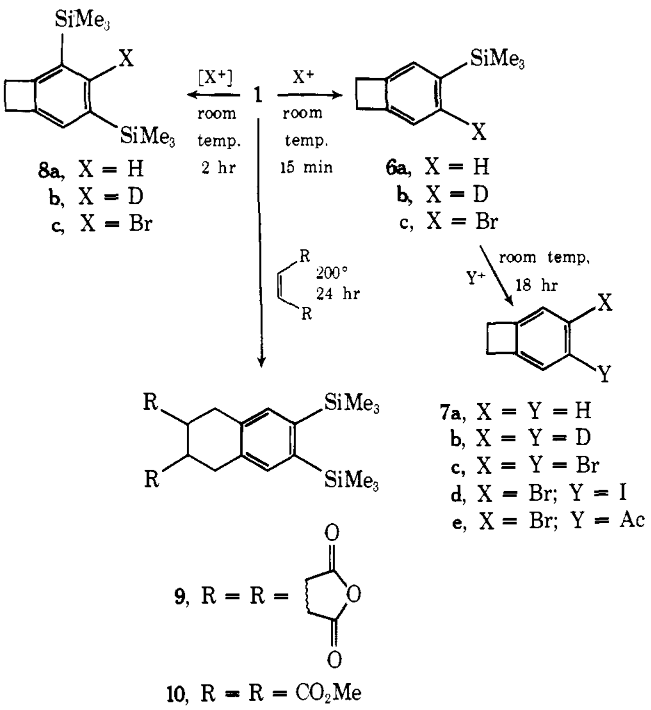
Addition of a solution of 1,5-hexadiyne (**2**) in *n*-octane to a refluxing solution of a fivefold excess of bis(trimethylsilyl)acetylene (**3**)[9] and catalytic amounts of η^5-cyclopentadienylcobalt dicarbonyl in *n*-octane during 72 hr using a syringe pump[10] leads to colorless crystals of compound **1** (>60%; mp 43-44°),[12,15] 30% of trimer **5**,[5] and 3% of the cyclobutadiene complex **4**[12] (ca. 40% based on initial catalyst), as a yellow oil and the only isolable cobalt containing molecule.



The high-yield formation of **1** is remarkable considering the strenuous conditions employed and the fact that **3** was thought to be unable to participate in acetylene cyclotrimerization reactions.[11b] The inevitable presence of Co^{III} ions in the reaction mixture (via traces of air) does not seem to lead to rearrangement of the bulky substituents as observed in *o*-di-*tert*-butylbenzenes.[13] The spectral data reveal that, not unexpectedly,[14] the benzene ring retains its aromatic character. The ^{13}C NMR spectrum[15] shows an upfield shift (ca. 4-7 ppm) for the proton-bearing aromatic carbons when compared with 1,2,3,4-tetrahydro-6,7-bis(trimethylsilyl)naphthalene[7] and other model systems,[16] a strong indication of increased strain in the system.

Further confirmation of this finding is found in the chemical behavior of **1**. Deuteriodesilylation of **1** in $CD_3COOD-CF_3COOD-CCl_4$ (1:1.5:3 by volume) exhibits pseudo-first-order kinetics and a reactivity of the first trimethylsilyl group 33 times higher than the second. Thus, in comparison with *o*-bis(trimethylsilyl)benzene[17] (protodesilyation rate ratio 17:1) fusion of the four-membered ring does not appear to increase the double bond character of the C_4-C_5 bond,[18,24] significantly. The reaction proceeds cleanly via monosilyl compound **6a**[19] to benzocyclobutene (**7a**) (>90%). Of all the recent syntheses of benzocyclobutene,[20] we regard this one to be the simplest and most straightforward. Deuterated acid leads to the deuterated derivatives **6b** and **7b**.[12] On the other hand, dilute acid (5-10%) rearranges[22] **1** to **8a** (mp 20-25°)[12] and **8b** (>75% deuterium incorporation), respectively. Thus, starting from **1** and its 3,6-dideuterio analog[7] various concentrations of deuterated or protic acid enable the formation of a large variety of deuterated benzocyclobutenes, of great utility in mechanistic and labeling studies on derived systems.[16,21]

The remarkable reactivity of the first trimethylsilyl group toward electrophiles makes compound **1** an excellent synthetic intermediate. Stepwise reaction with a first electrophile (X^+) followed by a second (Y^+) leads to functionalized compounds **6c** (mp 55-56°) and **7c** (mp 72-73°), **7d** (mp 49-51°), and **7e** (bp 100° (0.05 mm), microstill) in excellent yields.[12] The rearrangement pathway to **8** can be effectively suppressed by using excess X^+ or adding base (for example pyridine in the synthesis of **6c**) to speed up silyl abstraction.



Moreover, the two trimethylsilyl groups do not impair the ability of **1** to function as an *o*-xylylene synthon as exemplified by the essentially quantitative conversion to cycloadducts **9** and **10**, respectively.[12] Protodesilylation gives the known tetraline analogs.[23] Thus, using the *o*-bis(trimethylsilyl) unit in conjunction with the benzocyclobutene nucleus provides a most general synthetic entry with extensive control of substitution into systems containing the *o*-xylylene moiety. This should significantly improve the present scope of the use of benzocyclobutenes in synthesis.

Finally, we note with interest the exclusive formation of cobalt complex **4** in the synthesis of **1**. Also, no other trimethylsilyl containing oligomers nor a dimer of **2** could be isolated. Although **4** catalyzes the transformation of **2** to **5**, the rate of this process is very slow and no **1** is obtained, ruling out its role as the effective catalyst in the synthesis of **1**. Presumably **1** and **4**/**5** are formed via independent pathways.

Mechanistic details are under investigation.

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Stereochemical Course of the Reaction of Iron Carbonyl with Diastereomeric Vinyloxiranes

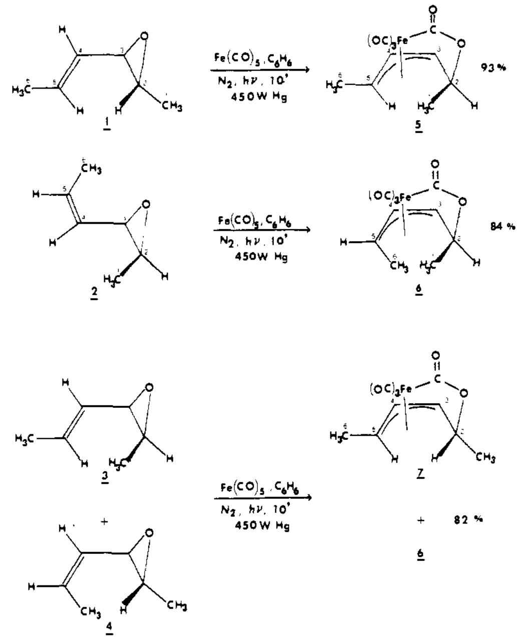
Sir:

The reaction of the vinylcyclopropyl system with iron carbonyl has been investigated extensively.[1] Recently the analogous reaction with vinyloxiranes has been reported.[2] This latter system appeared amenable to a detailed stereochemical analysis, and we report results of the reaction using diastereomeric vinyloxiranes.

Starting with the three pure dienes (*E,E*)-2,4; (*Z,Z*)-2,4; and (*Z,E*)-2,4-hexadienes, monoepoxidation yielded the vinyloxiranes **1**, **2**, **3** + **4**, respectively.[3] Both thermally and photochemically these compounds reacted with iron carbonyl to yield ferrelactone complexes. The thermal reaction yielded mixtures of diastereomers[5] but the photochemical reaction[6] proceeded *completely stereospecifically* (Scheme I).

The starting point for unraveling the stereochemical structures of complexes **5**, **6**, and **7** was an X-ray crystallographic determination on **7**. With this established, NMR studies enabled elucidation of the structures of **5** and **6**.

Scheme I



Ferrelactone **7** crystallized in the centrosymmetric orthorhombic space group *Pbca*. The cell dimensions were *a* = 12.0732 (16) Å, *c* = 12.2010 (15) Å, and ρ_{calcd} = 1.575 g/cm^3 for *Z* = 8. X-Ray diffraction data ($2\theta_{max}$ = 50°, Mo Kα radiation) were collected with a Picker FACS-1 diffractiometer and the structure was solved via Patterson, Fourier, and least-squares refinement methods. The final discrepancy indices were R_F = 3.21%, R_{wF} = 3.06% for 2377 independent reflections. The molecular structure, with selected bond distances, is shown in Figure 1.

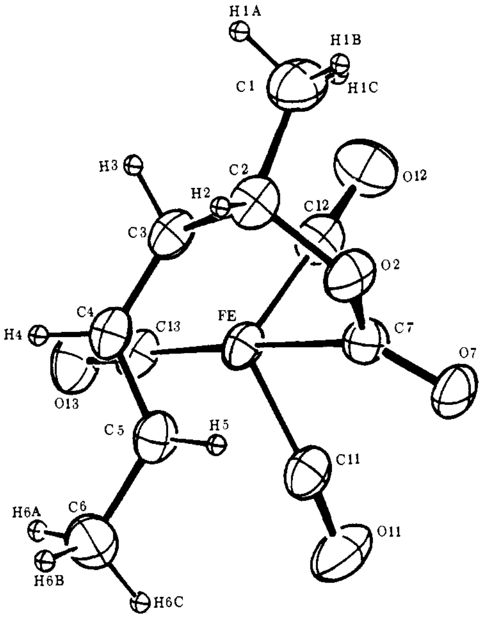


Figure 1. Molecular geometry of ferrelactone **7**. Important intraligand bond distances (in Å) are: C(1)-C(2) = 1.503 (5), C(2)-C(3) = 1.510 (4), C(3)-C(4) = 1.406 (3), C(4)-C(5) = 1.389 (4), C(5)-C(6) = 1.498 (4); C(2)-O(2) = 1.438 (3), O(2)-C(7) = 1.364 (3), C(7)-O(7) = 1.211 (3). Iron-carbon bond distances are: Fe···C(3) = 2.090 (2), Fe···C(4) = 2.077 (3), Fe···C(5) = 2.209 (3), and Fe-C(7) = 1.985 (2).

Using the ^{1}H NMR spectrum of **7** as a reference the relative stereochemistries of **5** and **6** were determined by analysis of coupling constants and induced chemical shifts (Table I). First, comparing **5** and **7** the only difference in coupling constant is the vicinal coupling $^{3}J_{2,3}$ of 4.0 Hz in **5**