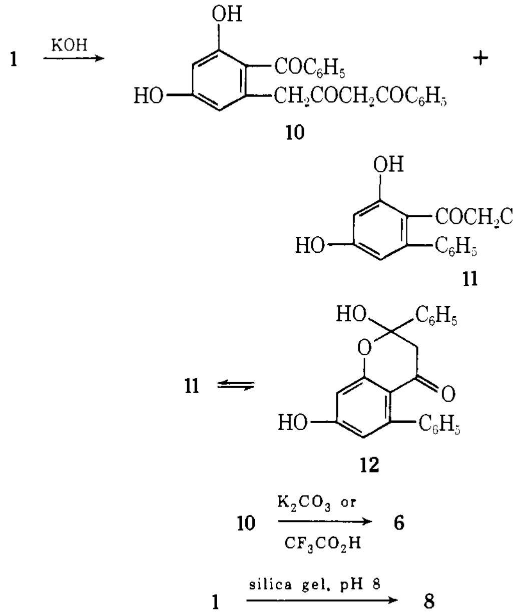
**Scheme III**



protons of the acetyl group peri to the phenyl substituent are highly shielded (δ 1.3). Ritchie and Taylor have described similar shielding of the acetyl protons of 1-acetoxy-8-phenylnaphthalene.[12]

By contrast with the above, treatment of **1** with silica gel (pH 8) gave 92% of **8**,[5] mp 240° dec (*in vacuo*). This naphthalenetriol is slightly air-sensitive but gives a stable triacetate,[5] mp 174°. The structure assignment for **8** rests primarily on the infrared spectrum which showed that the carbonyl group was intramolecularly hydrogen bound ($\nu_{C=O}$ 1630 cm$^{-1}$) and on the nmr spectrum of the triacetate derivative in which none of the acetate protons showed unusual shielding (δ 2.06, 2.29, 2.29). These observations exclude the other possible formulations for this naphthalenetriol. The compound is an analog of the aphid metabolite, 6-hydroxymusizin.[13]

Further studies of the formation of polycyclic aromatic compounds from polyketones **1–3** are in progress.

**Acknowledgment.** We are grateful for generous financial support by the U. S. Public Health Service (Research Grant GM-12848).

---

[12] E. Ritchie and W. C. Taylor, *Aust. J. Chem.*, 24, 2137 (1971).

[13] K. S. Brown, D. W. Cameron, and U. Weiss, *Tetrahedron Lett.*, 471 (1969).

[14] National Defense Education Act Trainee.

**Philip J. Wittek,[14] Thomas M. Harris***
*Department of Chemistry, Vanderbilt University*
*Nashville, Tennessee 37235*

*Received May 26, 1973*

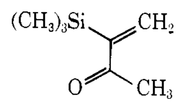
## Conjugate Addition–Annelation. A Highly Regiospecific and Stereospecific Synthesis of Polycyclic Ketones

*Sir:*

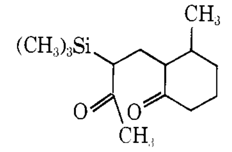
The regiospecific addition of vinyl ketones to kinetically generated enolates under the usual aprotic conditions has heretofore not been feasible due to two factors: (1) the extensive polymerization of vinyl ketones under these aprotic conditions and (2) relatively rapid proton transfer involving the vinyl ketones resulting in loss of enolate regiospecificity. Recently, Stork and Ganem[1] have introduced the α-silylated vinyl ketones as reagents designed to obviate the polymerization problem. However, they were unable to avoid extensive enolate equilibration in regio-unstable enolates.

During the course of a study of the chemistry of organocopper enolates,[2] we have found them regiochemically stable during alkylation reactions in all but the most hindered situations.[3] We were led to investigate the utility of the α-silylated vinyl ketones in combination with the lowered basicity and high enolate regiostability of organocopper enolates as a solution to the problem of annelation of regio-unstable kinetically generated enolates. At present the most convenient method of generation of copper enolates is *via* conjugate addition of lithium organocuprates.[4] A prior study of this overall process was beset by the aforementioned problems.[5]

Methyl-α-trimethylsilyl vinyl ketone (α-silyl-MVK) (**1**) (bp 72° (50 mm); 63%) was synthesized by a route analogous to that of Stork and Ganem.[6] Addition of cyclohexenone (1 equiv) to a solution of lithium dimethylcuprate (1 mol equiv) in ether at 0° for 1 hr followed by an ether solution of **1** (1 equiv) at −78°, stirring at −20° for an additional 1 hr, and quenching with aqueous ammonium chloride resulted in the isolation of a mixture of substances, primarily **2**, in good yield. The structure of **2** was inferred from the ir spectrum of the mixture which exhibited carbonyl absorption at 1715 cm$^{-1}$, as well as the characteristic singlet absorptions due to the methyl ketone δ 2.00 and trimethylsilyl δ 0.10 groups in the nmr spectrum. Further treatment of this crude mixture with 2% potassium hydroxide in methanol at reflux for 1 hr gave octalone **3** in 52% overall yield.[7] The structure of **3** was rigorously established by spectral comparison with the authentic octalone[8,9] and isomeric purity by comparison with **3** and **4** prepared as a mixture (23:77) from the enamine of 3-methylcyclohexanone and methyl



**1**



**2**

---

[1] G. Stork and B. Ganem, *J. Amer. Chem. Soc.*, **95**, 6152 (1973).

[2] We are currently pursuing direct evidence regarding the structure of the intermediates of 1,4 addition to α,β-unsaturated ketones; nevertheless we have noted distinct differences in the reactivity of these species compared to the corresponding lithium enolates; see also G. H. Posner and J. J. Sterling, *J. Amer. Chem. Soc.*, **95**, 3076 (1973).

[3] R. K. Boeckman, Jr., *J. Org. Chem.*, in press.

[4] Preliminary indications are that the organocopper enolate species generated by exchange have different reactivity and possibly differ structurally; see G. H. Posner, *Org. React.*, **19**, 1 (1972).

[5] R. A. Kretchmer, E. D. Hihelich, and J. J. Waldron, *J. Org. Chem.*, 37, 4483 (1972).

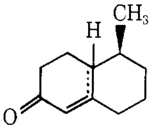
[6] B. Ganem, Ph.D. Dissertation, Columbia University, 1972.

[7] All compounds reported had satisfactory ir, nmr, and mass spectral data. Yields reported are for distilled material (Kugelrohr).

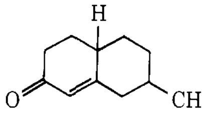
[8] We wish to thank Professor W. G. Dauben for providing spectral data of authentic **3** (equilibrium mixture of α,β and β,γ isomers) for comparison; see also R. A. Kretchmer and W. M. Schafer, *J. Org. Chem.*, 38, 95 (1973).

[9] The formation of **3** under equilibrating conditions seems to suggest that the thermodynamically favored equatorial isomer shown is the primary product. However, it is possible that small amounts of the epimeric methyl ketone are present. In any case, reactions done under conditions which equilibrate the isomers make this center potentially labile.

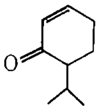
vinyl ketone.[10] Application of this annelation sequence to **5**[11] led also to the known octalone **6** [nmr δ 5.65 (br s, 1), 2.80–1.20 (m, 12), 1.20–0.8 (m, 9)] in 53% yield.[12,13] A single regio isomer is produced and the stereochemistry is assigned assuming equilibration has occurred.[14]



**3**

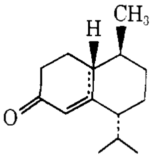


**4**

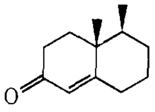


**5**

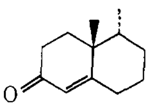
In the case of 2-substituted-2-cycloalkenones, the stereochemical result of the addition of the two groups is of interest. Treatment of 2-methyl-2-cyclohexenone in the usual way led to the isolation of octalones **7** and **8** (54%) in a ratio of ∼97:3 as determined by vpc (50-ft capillary column, Carbowax 20M, 140°). The structural assignments were made by comparison with authentic materials.[15] This represents a highly stereospecific process in which the groups enter in an overall trans addition.[16] By comparison, ordinary annelation of 2,3-dimethylcyclohexanone leading to **7** and **8** proceeds nonstereospecifically (3:2, trans:cis) and in poor yield (15%).[17] The overall stereoselectivity of the addition of **1** to 2-methyl-2-cyclohexenone is superior to the stereoselectivity achieved by alkylation of 2,3-dimethylcyclohexanone with 3-bromopropionate (9:1).[17]



**6**

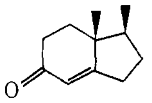


**7**

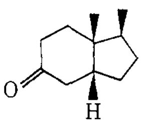


**8**

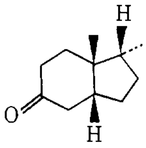
Direct annelation of cyclopentanones proceeds poorly in most cases due to the increased acidity of cyclopentanones and their propensity for self-condensation.[18] However, the addition–annelation sequence allows the preparation of hydrindenone **9** from 2-methyl-2-cyclopentenone in good yield (57%) and high stereospecificity. A sample of dihydroketone **10** (δ 0.93) (single quaternary methyl) was prepared by hydrogenation (palladium on charcoal) and compared to ketone **11** prepared by hydrogenation (palladium on charcoal) of **12**[19] after removal of the ketal. Inspection of models makes it clear that hydrogenation should occur only (or at least primarily) from the β face of the molecule. Ketone **11** was homogeneous by vpc and exhibited a single quaternary methyl resonance (δ 1.20) in the nmr spectrum; **10** had no absorption at δ 1.20 (detection limit 5%).[20] This indicates that ring size did not affect the stereochemical outcome.



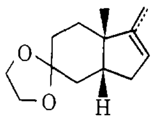
**9**



**10**

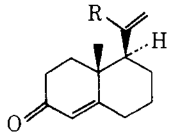


**11**

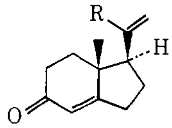


**12**

Groups other than methyl may be introduced *via* the cuprate, for example, the preparation of **13a** [nmr δ 5.57 (d, $J = 2$ Hz, 1), 4.87 (t, $J = 2$ Hz, 1), 4.70 (br s, 1), 1.8–1.0 (m, 11), 1.78 (q, $J = 2$ Hz, 3), 1.23 (s, 3)], **14a** [nmr δ 6.17–5.47 (m, 1), 5.62 (t, $J = 2$ Hz, 1), 5.17 (d, $J = 1$ Hz, 1), 4.93 (d of d, $J_1 = 5$ Hz, $J_2 = 2$ Hz, 1), 3.0–1.4 (m, 9), 1.07 (s, 3)], **13b**, and **14b** in yields of 50–70%.[21] The compounds **13a,b** and **14a,b** exhibited single sharp angular methyl resonances and were homogeneous by vpc criteria. The stereochemical assignments were made by analogy to compounds **7** and **9** since the arguments used to rationalize the stereochemical result[16] are all the more valid as the steric bulk of the allylic alkyl group increases.[22]



**13a**, R = $CH_3$
**b**, R = H



**14a**, R = H
**b**, R = $CH_3$

We are currently exploring the application of this method to various synthetic problems as well as alternative and more general methods of preparing copper enolates of known regiochemistry allowing the application of the annelation sequence to a wider range of substrates.

**Acknowledgment.** Acknowledgment is made to the donors of the Petroleum Research Fund, administered

---

[10] Comparison by vpc (10-ft Carbowax 20M at 175°) showed there to be ∼2% **4** present. The pure compounds were isolated by preparative vpc to establish identity.

[11] G. Stork and W. N. White, *J. Amer. Chem. Soc.*, 78, 4604 (1956).

[12] N. S. Gill and F. Lions, *J. Amer. Chem. Soc.*, 72, 3468 (1950).

[13] The hindered nature of the intermediate diketone rquired 24-hr heating with base for complete ring closure.

[14] Compound **6** was obtained as the equilibrium mixture of α,β and β,γ isomers. The thermodynamically favored all-equatorial isomer is most likely the major if not exclusive product under equilibrating conditions.

[15] We wish to thank Professor A. R. Pinder for providing spectral data for comparison.

[16] The stereochemical result is the expected one assuming antiparallel addition of the vinyl ketone to the half-chair cyclohexene in which the allylic alkyl group has assumed a pseudoaxial position in order to relieve A strain; see G. Stork, R. Danheiser, and B. Ganem, *J. Amer. Chem. Soc.*, **95**, 3414 (1973).

[17] E. Piers, R. W. Britton, and W. de Waal, *Can. J. Chem.*, 47, 4307 (1969).

[18] A notable exception is the annelation of cyclopentanone enamines and activated cyclopentanones; however, there are inherent limitations to substituent patterns which are obtainable; see G. Stork, A. Brizzolara, H. Landesman, J. Szmuskovicz, and R. Terrell, *J. Amer. Chem. Soc.*, 85, 207 (1963).

[19] Compound **12** was prepared from 9-methyl-$\Delta^{(1,8)}$-hydrindene-2,5-dione by the sequence: hydrogenation over palladium in ethanol; monoketalization with methyl ethyl ketone ketal; addition of methylmagnesium bromide; and dehydration with thionyl chloride and pyridine in ether at reflux.

[20] Attempts to resolve isomers **10** and **11** by vpc on several columns including capillary types were unsuccessful.

[21] The stereochemical outcome is inferred from the foregoing arguments (see ref 16). The yields of all reactions reported were not optimized. The yields of the cases utilizing vinyl cuprates were very much dependent upon the care taken in the preparation of the cuprate reagents.

[22] It is unlikely that stereochemical mixtures are present since the considerable magnetic anisotropy of the vinyl side chains would make coincidental overlap of the quaternary methyl signals highly improbable.

by the American Chemical Society, for support of this research.

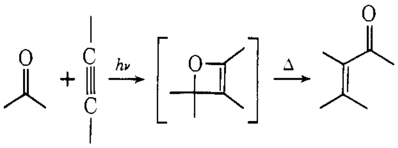
**Robert K. Boeckman, Jr.**
*Department of Chemistry, Wayne State University*
*Detroit, Michigan 48202*

*Received July 26, 1973*

## Detection of an Oxetene Intermediate in the Photoreaction of Benzaldehyde with 2-Butyne

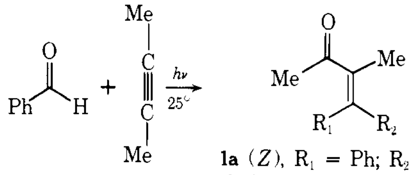
*Sir:*

Numerous papers dating back to 1956 have been published that describe the photoproduction of enones on irradiation of carbonyl compounds in the presence of acetylenes.[1] In all of these reports, an oxetene intermediate was assumed to have formed which was unstable and fragmented to the enone product. In none of these studies, however, was an oxetene isolated or detected.[2]



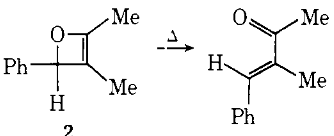
In 1969 the first unfluorinated oxetene, prepared by photolysis of 3,4-dimethyl-3-penten-2-one, was found to be stable at room temperature.[3] We therefore believed that certain stable oxetenes might be detected in the irradiation of carbonyl and acetylenic compounds. One such system is the benzaldehyde–2-butyne pair.[4]

Irradiation[5] of an undegassed $CH_2Cl_2$ solution containing 0.2 *M* benzaldehyde and 0.5 *M* 2-butyne for 4 hr at 20° gave a *ca.* 24% conversion (43% yield) to the known[6] (*Z*)- and (*E*)-enones, **1a** and **1b**, in a *ca.* 2:1 ratio (nmr). Independent experiments indicated that this ratio was the photostationary state and was not greatly affected by temperatures down to −78°. A similar irradiation at −78°, followed by nmr analysis at room temperature, showed only the *E* isomer **1b**. If this sample of the *E* isomer was cooled to −78° and irradiation continued, the photostationary state of enone **1** was attained. Our conclusion is that enone **1b** was *not* photochemically generated at −78°, but rather was stereospecifically formed from an oxetene in a thermal process on warming.

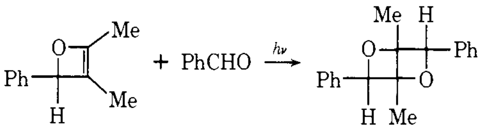


**1a** (*Z*), $R_1$ = Ph; $R_2$ = H
**1b** (*E*), $R_1$ = H; $R_2$ = Ph

Specific attempts to trap the oxetene **2** at −78° or above have failed. In all cases ($O_3$, $Br_2$, $H_2/Pt$, $B_2H_6$), only the reaction products from enone **1b** were detected. As we expected,[7] however, a [2 + 2] cycloaddition of benzaldehyde with the oxetene **2** was found at low temperature where the oxetene was stable. We have assigned the structure of the novel fused oxetane **3**[8] as containing the 2,5-dioxa[2.2.0]hexane skeleton rather than the 2,6-dioxa[2.2.0]hexane framework because of equivalent methyl signals in the nmr (δ 1.02 (s, 6 H)).



**2** **1b**



**2** **3**

In an attempt to actually observe the oxetene **2**, a reaction solution was prepared by irradiation at −78°. Most of the $CH_2Cl_2$ and excess 2-butyne was removed at −45° under reduced pressure. A 100-MHz nmr spectrum at −45° in $CFCl_3$ solution showed two equally intense singlets for oxetene **2** at δ 1.96 and 1.67 ppm[9] that disappeared on warming and did not reappear on cooling.

In their place, singlets appeared at δ 2.44 and 2.07 ppm which correspond to the methyl groups of (*E*)-enone **1b**.[10] The methine hydrogen of oxetene **2** (assigned at δ 5.81) was partially obscured by several minor temperature-independent absorptions that were not investigated.

Oxetene **2** was found to have a half-life of several hours at −35°. From temperature-dependent nmr

---

[1] (a) G. Buchi, J. T. Kofron, E. Koller, and D. Rosenthal, *J. Amer. Chem. Soc.*, 78, 876 (1956); (b) D. Bryce-Smith, A. Gilbert, and M. G. Johnson, *Tetrahedron Lett.*, 2863 (1968); (c) S. P. Pappas and B. C. Pappas, *ibid.*, 1597 (1967); (d) D. Bryce-Smith, G. I. Fray, and A. Gilbert, *ibid.*, 2137 (1964); (e) H. E. Zimmerman and L. Craft, *ibid.*, 2131 (1964); (f) S. Farid, W. Kothe, and G. Pfundt, *ibid.*, 4147 (1968); (g) S. P. Pappas and N. A. Portnoy, *J. Org. Chem.*, **33**, 2200 (1968); (h) H. J. T. Bos, H. T. Van Der Bend, J. S. M. Boleij, C. J. A. Everaars, and H. Polman, *Recl. Trav. Chim. Pays-Bas*, **91**, 65 (1972); (i) H. J. T. Bos and J. S. M. Boleij, *ibid.*, 88, 465 (1969); (j) H. Polman, J. S. M. Boleij, and H. J. T. Bos, *ibid.*, **91**, 1088 (1972); (k) S. Ficini and A. Krief, *Tetrahedron Lett.*, 2497 (1967); (l) T. Miyamoto, Y. Shigemitsu, and Y. Odaira, *Chem. Commun.*, 1410 (1969); (m) J. A. Barltrop and B. Hesp, *J. Chem. Soc. C*, 1625 (1967).

[2] Some photoreactions evidently by-pass reasonable ground-state intermediates. For example, Buchardt has failed to detect an oxaziridine or any other intermediate with a lifetime greater than $10^{-9}$ sec in the photolysis of quinoline *N*-oxides to carbostyrils and oxazepines: Organic Colloquium Series, University of Rochester, Rochester, N. Y., Feb 2, 1973. For a recent paper, see O. Buchardt and P. L. Kumler, *Acta Chem. Scand.*, **23**, 2149 (1969). Also, Arnold has suggested that the excess vibrational energy of a generated oxetene may cause fragmentation before collisional deactivation to a stable molecule; see D. R. Arnold, *Advan. Photochem.*, **6**, 341 (1968).

[3] L. E. Friedrich and G. B. Schuster, *J. Amer. Chem. Soc.*, **91**, 7204 (1969).

[4] Irradiation of *trans*-stilbene oxide gave benzaldehyde which added to 2-butyne to yield (*Z*)- and (*E*)-3-methyl-4-phenyl-3-buten-2-one; see H. Kristinsson and G. W. Griffin, *J. Amer. Chem. Soc.*, 88, 1579 (1966).

[5] Hanovia 450-W medium-pressure mercury lamp through Pyrex.

[6] L. E. Hightower, L. R. Glasgow, K. M. Stone, D. A. Albertson, and H. A. Smith, *J. Org. Chem.*, **35**, 1881 (1970), report the *E* isomer. The (*Z*)-enone was apparently uncharacterized until now: nmr ($CCl_4$) δ 7.07 (s, 5), 6.05 (d, *J* = 1.5 Hz, 1), 1.94 (d, *J* = 1.5 Hz, 3), 1.86 (s, 3).

[7] 2,3,4,4-Tetramethyloxetene reacts with benzophenone triplet to give a [2 + 2] cycloadduct; unpublished results of L. E. Friedrich and G. B. Schuster; see G. B. Schuster, Ph.D. Thesis, University of Rochester, Rochester, N. Y., 1971. Professor J. C. Dalton and S. J. Tremont have prepared the only other known example of this new class of compounds at the University of Rochester, 1973; *Tetrahedron Lett.*, in press.

[8] Oxetane **3**: mp 89–90°; ir ($CCl_4$) 3065, 3033, 1606, 1493, 1453, 1387, 1137, 979 (very strong), 700 $cm^{-1}$; nmr ($CCl_4$) δ 7.44 (s, 10), 6.17 (s, 2), 1.02 (s, 6); mass spectrum (70 eV) 266 (parent, 6), 248 (23), 160 (100), 159 (98), 145 (44), 117 (56), 105 (42), 43 (34). *Anal.* Calcd for $C_{18}H_{18}O_2$ (266.32): C, 81.17; H, 6.81. Found: C, 81.03; H, 6.55.

[9] Relative to $CH_2Cl_2$ at δ 5.30.

[10] At room temperature in $CCl_4$ enone **1b** also possesses a vinyl H at δ 7.32, barely distinguishable from the phenyl absorptions at δ 7.21.