of toroidal permanent magnets (500 G axial field) and enclosed in a 2-L Pyrex envelope that is continuously evacuated by a Varian VHS-2 diffusion pump charged with Convalex 10 polyphenyl ether. The remaining length (120 cm) of the reaction vessel is wrapped with ten layers of no. 14 magnet wire. A constant current of 2.6 A is maintained in this solenoid to give an axial field ≥200 G throughout the entire reaction vessel. The temperature of the reaction vessel during a run is between 320 and 330 K as a consequence of heat generated by the solenoid.

The same procedures as previously described were used. Electron energy was determined by biasing the filament negative to the reaction vessel, which is grounded. At 70 eV the electron current varied from 10 to 80 μA, with roughly half the current measured from the reaction vessel walls and half from a set of collector baffles between the reaction vessel and the liquid nitrogen cold trap. Three runs were performed at pressures between 0.8 and 2×10^{-4} Torr, and a control run at 8 V was performed in the same pressure range. GLC analyses were performed on the dimethylsulfolane column. From addition of a known quantity of *cis*-4-methyl-2-pentene as a standard to the control and to one of the 70-eV runs, absolute yields were determined. Normalized C_5H_{10} yield for the 70-eV run was 4.5 μmol A^{-1} s^{-1}. In the control run a current ≤1 μA was measured in the reaction vessel; the C_5H_{10} yield per unit time (not normalized for electron current) was 15 pmol s^{-1} and showed a value of **2/3** = 0.7 (no other isomers were detected). A final run was performed in the pressure range $1.2-1.4 \times 10^{-3}$ Torr with currents on the order of 10 μA measured on the walls of the reaction vessel and ≤1 μA at the collector.

Acknowledgment. The author is grateful to Professor Richard William Johnson for helpful comments. Acknowledgment is made to the donors of the Petroleum Research Fund, administered by the American Chemical Society, for support of this research.

References and Notes

(1) (a) Goodman, N.; Morawetz, H. *J. Polym. Sci., Part A-2* **1971,** *9,* 1657–1668. (b) Connor, H. D.; Shimada, K.; Szwarc, M. *Macromolecules* **1972,** *5,* 801–807. (c) Shimada, K.; Moshuk, G.; Connor, H. D.; Caluwe, P.; Szwarc, M. *Chem. Phys. Lett.* **1972,** *14,* 396–403. (d) Winnik, M. A. *Acc. Chem. Res.* **1977,** *10,* 173–179. (e) Illuminati, G.; Mandolini, L.; Masci, B. *J. Am. Chem. Soc.* **1977,** *99,* 6308–6312.
(2) Breslow, R.; Winnik, M. A. *J. Am. Chem. Soc.* **1969,** *91,* 3083–3084.
(3) (a) Winnik, M. A.; Lee, C. K.; Kwong, P. T. Y. *J. Am. Chem. Soc.* **1974,** *96,* 2901–2907. (b) Green, M. M.; Armstrong, M. W.; Thompson, T. L.; Sprague, K. J.; Hass, A. J.; Artus, J. J.; Moldowan, J. M. *J. Am. Chem. Soc.* **1976,** *98,* 849–850, and references cited therein.
(4) Wolf, J. F.; Staley, R. H.; Koppel, I.; Taagepera, M.; McIver, R. T., Jr.; Beauchamp, J. L.; Taft, R. W. *J. Am. Chem. Soc.* **1977,** *99,* 5417–5429.
(5) Morton, T. H.; Beauchamp, J. L. *J. Am. Chem. Soc.* **1975,** *97,* 2355–2362; **1977,** *99,* 1288.
(6) Burns, F. B.; Morton, T. H. *J. Am. Chem. Soc.* **1976,** *98,* 7308–7313. Note that the oxygen was inadvertently omitted from the structure drawn for *n*-butyl phenyl ethers **1-4.**
(7) Marinelli, W. J.; Morton, T. H. *J. Am. Chem. Soc.* **1978,** *100,* 3536–3539; **1979,** *101,* 1908.
(8) Derrick, P. J.; Falick, A. M.; Lewis, S.; Burlingame, A. L. *J. Phys. Chem.* **1979,** *83,* 1567–1573.
(9) (a) MacLeod, J. K.; Djerassi, C. *J. Am. Chem. Soc.* **1966,** *88,* 1840–1841. (b) Yeo, A. N. H.; Djerassi, C. *Ibid.* **1972,** *94,* 482–484.
(10) Benoit, F. M.; Harrison, A. G. *Org. Mass Spectrom.* **1976,** *11,* 599–608.
(11) Borchers, F.; Levsen, K.; Beckey, H. D. *Int. J. Mass Spectrom. Ion Phys.* **1976,** *21,* 125–132.
(12) Nibbering, N. M. M. *Tetrahedron* **1973,** *29,* 385–390.
(13) DeFrees, D. J.; McIver, R. T., Jr.; Hehre, W. J. *J. Am. Chem. Soc.* **1977,** *99,* 3853–3854.
(14) Kobayashi, T.; Nakagura, S. *Bull. Chem. Soc. Jpn.* **1974,** *47,* 2563–2572.
(15) Benson, S. W. "Thermochemical Kinetics", 2nd ed.; Wiley-Interscience: New York, 1976.
(16) Bowen, R. D.; Williams, D. H. *Int. J. Mass Spectrom. Ion Phys.* **1979,** *29,* 47–55, and references cited therein.
(17) Based on heats of formation for phenoxyl = 0.2 eV (5 kcal/mol) [Paul, S.; Back, M. H. *Can. J. Chem.* **1975,** *53,* 3330–3338], for *n*-butyl phenyl ether molecular ion ≃6.5 eV (150 kcal/mol, ref 6), and for *sec*-butyl cation = 8.0 eV (184 kcal/mol, ref 19). The curve in Figure 1 beyond 3 Å is based on ion–induced dipole attraction only, using a classical r^{-4} potential and a mean polarizability for phenoxyl of 10 Å^3 [Stuart, H. A. In Landolt-Bornstein, 6th ed., 1951; Vol. I (3), pp 509–517].
(18) Jasinski, J. M.; Rosenfeld, R. N.; Golden, D. M.; Brauman, J. I. *J. Am. Chem. Soc.* **1979,** *101,* 2259–2265.
(19) (a) Saunders, M.; Vogel, P.; Hagen, E. L.; Rosenfeld, J. *Acc. Chem. Res.* **1973,** *6,* 53–59. (b) Bittner, E. W.; Arnett, E. M.; Saunders, M. *J. Am. Chem. Soc.* **1976,** *98,* 3734–3735.
(20) Houle, F. A.; Beauchamp, J. L. *J. Am. Chem. Soc.* **1979,** *101,* 4067–4074.
(21) Lawler, R. G.; Barbara, P. F.; Jacobs, D. *J. Am. Chem. Soc.* **1978,** *100,* 4912–4914, and references cited therein.
(22) Friedman, L.; Shechter, H. *J. Am. Chem. Soc.* **1959,** *81,* 5512–5513.
(23) (a) Frey, H. M. *Trans. Faraday Soc.* **1960,** *56,* 51–54. (b) Flowers, M. C.; Frey, H. M. *J. Chem. Soc.* **1959,** 3953–3957; **1962,** 1157–1165.
(24) Su, T.; Bowers, M. T. *J. Am. Chem. Soc.* **1973,** *95,* 7611–7613.
(25) Burns, F. B. Ph.D. Thesis, Brown University, 1976.
(26) (a) Dymerski, P. P.; McLafferty, F. W. *J. Am. Chem. Soc.* **1976,** *98,* 3734–3735. (b) Ausloos, P. A.; Shold, D. M. *Ibid.* **1978,** *100,* 7915–7919.
(27) Sneen, R. A. *Acc. Chem. Res.* **1973,** *6,* 46–53.
(28) Freiser, B. S., personal communication.
(29) Sullivan, S. A.; Beauchamp, J. L. *J. Am. Chem. Soc.* **1977,** *99,* 5017–5022.
(30) Danree, B.; Seyden-Penne, J. *Bull. Soc. Chim. Fr.* **1967,** 415.
(31) Holmes, J. L.; Tong, D. C. M.; Rye, R. T. B. *Org. Mass Spectrom.* **1972,** *6,* 897–903.
(32) Gilman, H., Blatt, A. H., Eds., "Organic Syntheses", Collect. Vol. I, 2nd ed.; Wiley: New York, 1941; pp 459–462.
(33) Butlerow, A. *Justus Liebigs Ann. Chem.* **1873,** *170,* 151–162.

γ-Alkylation of α,β-Unsaturated Ketones. γ-Arylsulfonyl Groups as Regioselective Control Elements

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Abstract: A reaction sequence for γ-alkylation of α,β-unsaturated ketones has been proposed and tested with some success. γ-(Phenylsulfonyl) groups are (1) introduced into the substrate; (2) present during alkylation of the resulting highly delocalized carbanions; (3) finally removed to leave the otherwise inaccessible γ-alkylation product.

Introduction

α,β-Unsaturated ketones are popular and versatile intermediates in organic synthesis.[1-3] Moreover, they are easily preparable by a plethora of methods from various starting materials. These structures can be utilized for both thermal [4 + 2] and photochemical [2 + 2] cycloadditions. New individual carbon-carbon bonds can be formed by highly selective 1,2- or 1,4-nucleophilic additions onto the normally electrophilic enone framework. On the other hand, regioselective

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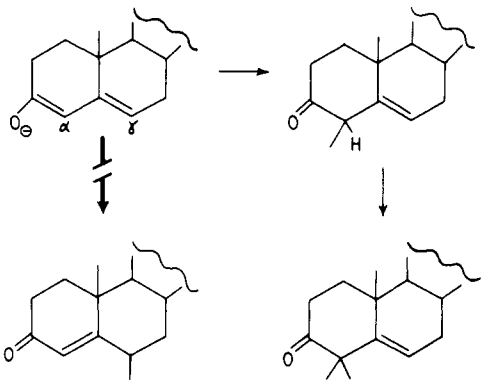
Scheme I



deprotonation of α,β-unsaturated ketones inverts their electronic character, yielding two types of nucleophilic conjugate bases,[1,4] thus expanding the possibilities for heterolytic bond formation. The kinetic dienolate[1,4] reacts with alkyl halides at the α′ position and the thermodynamic dienolate provides opportunities for electrophilic attack at the α and/or γ positions, at least theoretically. Moreover, more powerful electrophiles such as carboxylic anhydrides and silyl halides react at oxygen in both types of anions,[1,4] as well as the parent enones themselves. It is clear, therefore, that almost every atom with actual or latent donor or acceptor capabilities from C-α′ through the carbonyl group (both C and O) to the β carbon can be used in selective, classical transformations. The concept of reactivity "umpolung"[5] by means of synthetic equivalent groups provides additional options.

This research was addressed to a particularly serious limitation upon regioselectivity of electrophilic alkylation in thermodynamic dienolates derived from α,β-unsaturated ketones. Although such enolates are easily accessible,[1,4] by allowing initially formed enolate to equilibrate with excess ketone, they invariably undergo irreversible C-alkylation at the α position,[6] even when that site has already undergone monoalkylation and/or is sterically quite congested[7,8] (illustrated in Scheme I with a steroidal enone such as cholestenone). Direct *inter*molecular γ-alkylation of simple enones has not been achievable[9] except in β-enamino ketones[10] derived from secondary amines. Intramolecularly such bonding can be made to predominate in geometrically favorable circumstances,[11] especially under conditions where "late" transition states may be involved. Since a substantial number of 6-methyl steroidal 4-en-3-ones are of use in medicine, it would be desirable to have the capability for direct γ-alkylation in the arsenal of the synthetic chemist. At present, synthetic intermediates or products formally containing γ-alkylated α,β-unsaturated ketone structures are *indirectly* generated, often by rather ingenious pathways.[12-15] Such solutions are not general, nor do they contribute to resolving the basic dilemma of unfavorable electron distributions in dienolates.[6]

Substantial progress has been made in achieving γ-alkylation of α,β-unsaturated carboxylic acids[16] and secondary anilides,[17] primarily via their dianions. A similar multiple-anion strategy can be envisioned for γ-alkylation of unsaturated ketones. However, our initial efforts[18] concerned the effect of γ substituents upon regioselectivity of thermodynamic dienolate alkylations. Our working hypothesis has been to evaluate α,β-unsaturated ketones with γ substituents that also had anion-stabilizing capabilities. There would then arise, on deprotonation, highly delocalized "cross-bred" allyl anions (CBAs) with a better chance to react at *both* ends of the resonance hybrid. Hagemann's ester, a well-known example of this type, is generally found[19] to monoalkylate primarily α to the ketone carbonyl group, rather than the ester, although *both* monosubstituted allyl anions themselves are α directing during anion alkylation.[9,20] However, when a methyl group is already present at the α position of Hagemann's ester (and steric effects at both α and γ positions are accordingly more equal in magnitude), alkylation does indeed occur *at both positions in roughly equal amounts*.[21]

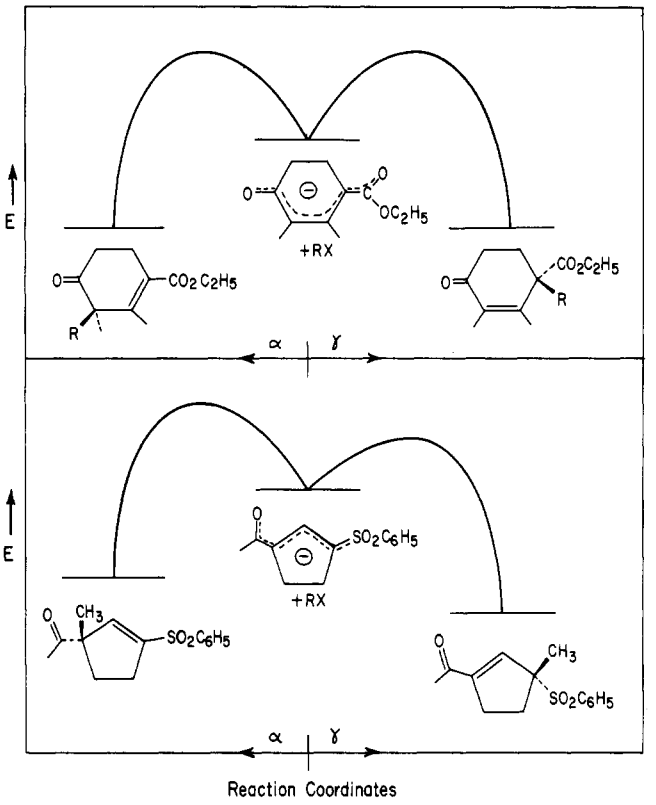
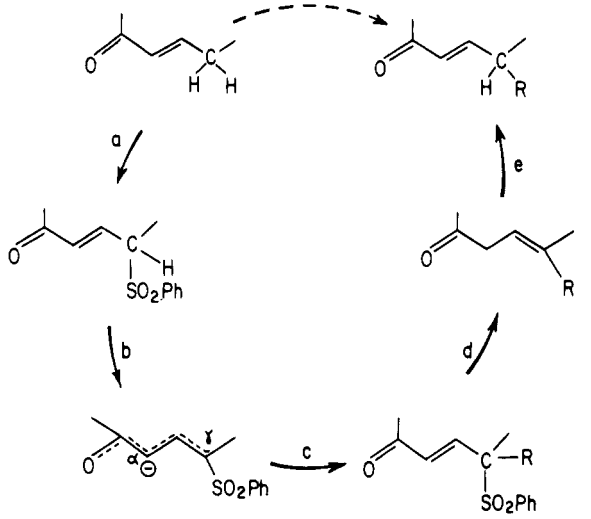


Figure 1.

We hypothesized that, when the degree of conjugative stabilization increases in a series of similar delocalized carbanions (other things being equal), the transition state for alkylation will appear "later" on the reaction coordinate (Hammond postulate). That is, *product stability* will be more significant in determining the relative stabilities of such late transition states from ambient anions with a given electrophile. The proportions of products would vary accordingly. For example, Trost and Melvin[15] observed greater regioselectivity in favor of more conjugated products during transfer alkylation involving anions derived from Meldrum's acids ($pK_a \sim 4.8$) than methylmalonates ($pK_a \sim 15$). Thus, if the α and γ substituents flanking an allyl anion had *complementary* conjugative tendencies (as in para-disubstituted benzenes such as *p*-nitroaniline and *p*-methoxybenzaldehyde), so as to greatly favor one double bond isomer in the alkylation product, the relative transition state energies might partially reflect this effect. A schematic reaction coordinate diagram for α-methylated Hagemann's ester[21] and a plausible, sterically balanced CBA for preferred γ-alkylation (vide infra) are shown in Figure 1. The selection of the γ-sulfonyl group as a prime candidate for the role of transient *regioselective control element* was based on the pronounced tendency of this group (and sulfoxide also) to *deconjugate* from double bonds,[22] provided that the latter is equally substituted in the β,γ isomer. Carbonyl substituents, on the other hand, have strong conjugative tendencies.[23] It was expected that placement of sulfonyl and carbonyl groups at the α and γ positions of an allyl system would result in an overwhelming preference for that tautomer with an α,β-unsaturated carbonyl structure. This complementarity of conjugative effects is in marked contrast to the situation in Hagemann's ester inter alia wherein the individual conjugating tendencies[23] of the two groups would partially or completely cancel each other. Moreover, the substantial acidity of β-keto sulfones[24]

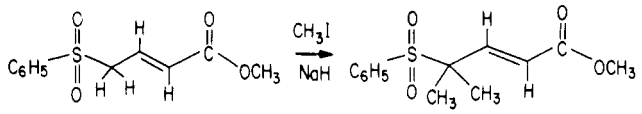
Scheme II. Sequence of γ-Alkylation of α,β-Unsaturated Ketones



a) introduce control element; b) form conjugate base by γ-H abstraction; c) react with alkyl halide; d) reductive desulfonylation; e) reconjugation, if needed.

(vinylogs such as those herein would be even more acidic, because of extended conjugation in the anions) suggests that alkylations of such conjugate bases will indeed be relatively endothermic, with "late" transition states as desired.

At the outset of our investigations, we were aware of Julia's partially successful γ-prenylations of γ-(phenylsulfonyl)tiglate esters[25] and had ourselves made similar observations with other alkylating agents in the corresponding crotonate esters. Thus, while dienoate anions derived from γ-(thiomethyl) crotonate[26] and γ-(sulfoxyphenyl) crotonate[27] still undergo predominant α-alkylation, we found that excess methylation of methyl γ-(phenylsulfonyl) crotonate under monoanion conditions gave reasonable yields of γ,γ-dimethyl product.[28] These encouraging results, which buttressed our mechanistic rationalization (above), prompted us to undertake the evaluation of γ-sulfonyl substituents in α,β-unsaturated ketones for altering the regioselectivity of thermodynamic dienolate alkylations. Scheme II outlines the proposed sequence.



Methods and Results

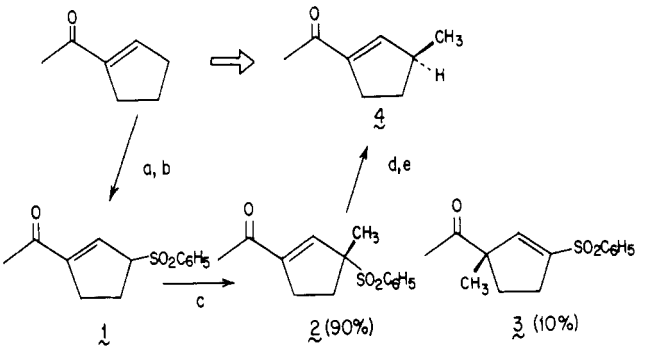
1-Acetyl-3-(phenylsulfonyl)cyclopentene (**1**) was initially selected to test the ideas discussed in the previous section for altering regioselectivity. The well-delocalized conjugate base of **1** is relatively symmetrical, except for the α and γ substituents themselves, and would presumably undergo monoalkylation only with excess base. Accordingly, 1-acetylcyclopentene was reacted with *N*-bromosuccinimide and the crude γ-bromo ketone (containing isomeric impurities) reacted with sodium benzenesulfinate in *N,N*-dimethylformamide. The low yield of **1** was not optimized; moreover, nucleophilic displacements upon γ-halo α,β-unsaturated ketones have on occasion led to isomeric substitution products[28,29] (e.g., S_N2'). Fortunately, there are several alternative sequences available for stubborn cases, e.g., using electrophilic sulfenylation of dienolates[30] and free-radical rearrangement of dienol sulfonates.[31] These modes of incorporating the γ-sulfonyl control element still begin with an α,β-unsaturated ketone.

Ketone **1** did not equilibrate to the vinyl sulfone tautomer, as predicted, and its sodium salt, generated in *N,N*-dimethylformamide (DMF) by means of sodium hydride, gave back pure **1** upon quenching into dilute acetic acid. Thus γ-protonation occurred under kinetic *and* thermodynamic control. When **1** was ionized as above and reacted with methyl iodide, a quantitative yield of methylation products **2** and **3** was obtained. Spectral examination (NMR and infrared) quickly revealed that the desired γ-methylated ketone **2** predominated by ca. 10:1 (by NMR integration, see below) over the unwanted α-alkylated **3**, which made isolation of pure **2** a simple matter. This satisfying result immediately assured us that our approach justified further investigation, provided that the regioselective control element could be expeditiously removed. Several methods for disposing of the γ-(phenylsulfonyl) group were evaluated (see below), the most convenient being zinc dust in acetic acid, which gave the deconjugated isomer of **3** prior to HCl-catalyzed reconjugation of the double bond. The characterization of γ-alkylation products from **1** and related cyclopentenes such as **10** was facilitated by several recurring spectral features: (1) disappearance of the γ-proton multiplet in **1** at δ 4.5 indicated consumption of starting material, while retention of the β-vinyl proton as a *singlet* at δ 6.4 (±0.1) ppm and the acetyl signal at 2.3 ppm suggested introduction of a γ-alkyl group; (2) infrared carbonyl absorption due to retained conjugation at 1675–1680 cm^{-1} (neat, or in Nujol mull for the purified solids); (3) ultraviolet absorption (ε 10 000–20 000) for the conjugated ketone at ca. 240–242 nm corresponding essentially to the absorption of **1** itself. α-Alkylation products, which were not isolated in pure condition, were spotted by their expected infrared carbonyl bands at ca. 1710 cm^{-1} and in the NMR spectrum by the β-vinyl proton "singlet" (conjugated to sulfone) at 6.7–6.9 ppm, along with the shifted acetyl signal at 2.1 ppm. The α-/γ-alkylation ratios in crude product mixtures were obtained directly by integration of the two well-separated vinyl proton signals and are estimated to be accurate to 2–3% or better.

The six-membered ring homologue **5** was synthesized from 1-acetylcyclohexene by the same series of steps as were used in preparing **1**, but in better overall yield. Methylation of the sodium salt of **5** in DMF occurred in over 90% isolated yield and again favored γ-alkylation (→**6**) but this time by only a 3:1 ratio. The vinyl proton resonances are shifted slightly downfield from the values for five-membered rings, appearing at δ 6.74 in **6** and δ 7.06 in **7**, the product of α-alkylation.

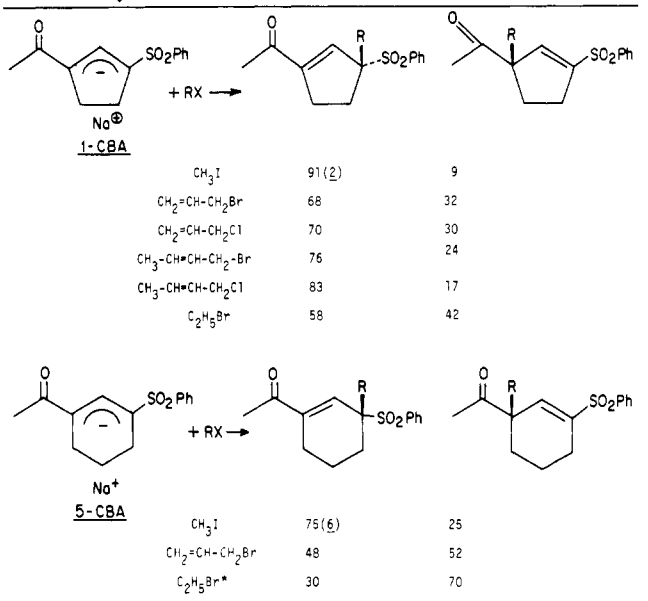
We have carried out a variety of alkylation experiments with both **1** and **5** using the sodium or potassium salts (usually the former) generated via the metal hydrides. The main findings[32] are recorded in Table I. Reaction temperatures were usually 0–25 °C and the preferred solvents were pure DMF or tetrahydrofuran containing at least 3 equiv of hexamethylphosphoramide (HMPA). As expected for highly stabilized anions,

Scheme III. A Typical γ-Alkylation Sequence



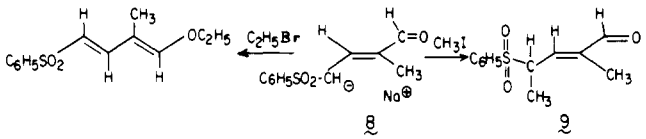
a) NBS, CCl_4, AIBN; b) $C_6H_5SO_2Na$, DMF; c) NaH, CH_3I; d) Zn, CH_3CO_2H; e) H^+.

Table I. Alkylation Selectivities in **1** and **5**



*Ca. 25% of this product was O-alkylate.

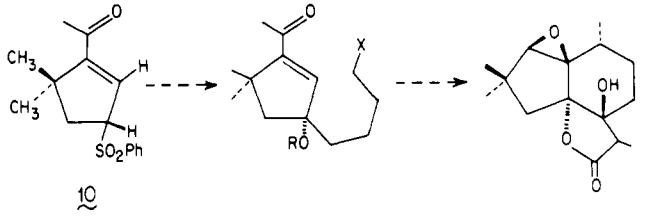
only poor yields at best resulted when alkylations were attempted with potassium *tert*-butoxide and *tert*-butyl alcohol and/or tetrahydrofuran. Various halogen leaving groups (usually the bromide) were employed without major differences in product distribution; chlorides were usable only in *allylic* systems. It is clear that alkyl halides with *any* α branching (i.e., other than methyl) are more hindered to backside attack at the site adjacent to the bulky sulfonyl group in the anions derived from **1** and **5** than at the less hindered site adjacent to the smaller acetyl group. The sensitivity of the γ-alkylation approach to steric effects (like any S_N2 reaction) is even more dramatically illustrated with α-methyl-γ-(phenylsulfonyl)crotonaldehyde (**8**). Methylation gives predominantly γ-alkylation product **9**, in pleasing contrast with



8 **9**

the α-prenylation of 2-pentenal.[33] The structure of **9** was established by first alkylating phenyl prenyl sulfone and then oxidizing the appropriate allylic methyl group with selenium dioxide, to give the same compound by an alternate path. However, merely switching to ethyl bromide results in overwhelming O-alkylation of **8**, an occurrence also noted by van der Gen et al. with primary and secondary alkyl iodies other than methyl.[33] Allyl bromide and β-methallyl chloride gave complex mixtures with **8**, dampening our hopes that **8** might be a viable synthon for "head-functionalized" terpenes.

From the foregoing results it is clear that steric factors can adversely affect the γ/α ratios in alkylation of these γ-substituted α,β-unsaturated ketones. Nevertheless, the trends are clearly in the right direction, especially when compared with the uniformly overwhelming α selectivities invariably observed with numerous simple dienolate (and dienamine) nucleophiles, which presumably alkylate via more "reactant-like" transition states regardless of steric hindrance at the α position.[5,7-9] One logical modification of the γ-substituent strategy would be to use smaller groups; we have noted no improvement, however, upon replacing γ-$PhSO_2$ by γ-CH_3SO_2 in **5**. In the meantime, parallel efforts were underway to apply the initially favorable γ-alkylation results in natural-products synthesis. In particular, we envisioned that ketone **10** would be an early precursor

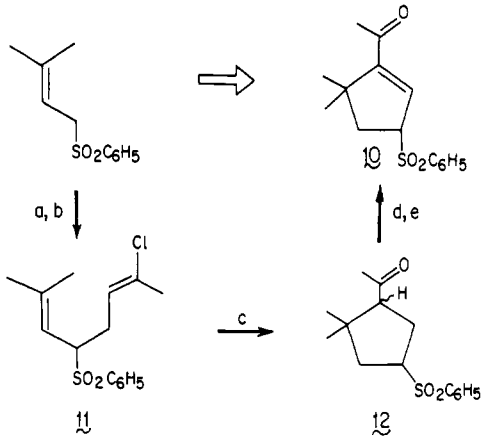


10

to several classes of sesquiterpenes such as alliacolide,[34] via γ-alkylation steps inter alia. In the conjugate base derived from **10** the steric effect of the *gem*-dimethyl groups adjacent to C_α might counter that of the γ-phenylsulfonyl group at C_γ without altering the electronic effect of the latter. The hoped-for outcome would be a greater tendency, compared with **1**, for γ-alkylation to prevail, even with more hindered alkyl halides. This expectation indeed proved to be the case (vide infra).

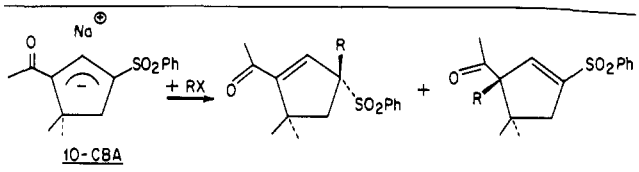
The synthesis of ketone **10** did not simply entail the incorporation of the γ-(phenylsulfonyl) group into an existing acetylcyclopentene, but rather illustrates a complementary way of preparing such systems beginning with sulfone anion alkylation (→**11**). Chloro olefin annelation[35] of the dienic substrate **11** efficiently generated the saturated cyclopentanoid keto sulfone **12** as a 1:1 mixture of cis and trans isomers. The requisite α,β unsaturation was introduced last, as shown in Scheme IV. With an expeditious and reproducible route to **10** in hand, a variety of alkylations of the conjugate base (usually the sodium salt in DMF) were attempted, beginning with methyl iodide and proceeding to allylic and other primary substrates and finally to isopropyl iodide. In most cases, alkylation yields were ≥90%. The pertinent results are summarized in Table II; as before, γ/α ratios were obtained by NMR spectroscopy, using the integrated intensities of the vinyl protons at ca. δ 6.4 (for γ-alkylated products) and ca. 6.8 (for α-alkylated products). γ-Alkylation products **13–15** were easily purified by crystallization and their physical properties are recorded in the Experimental Section. It is clear that the bulkiness of the *gem*-dimethyl group in **10**-CBA nicely counters the otherwise adverse steric effects of the γ-(phenylsulfonyl) directing group, as was encountered with **1** and **5**. The fact that compounds **13, 14,** and **15** are easily isolated in pure state demonstrates that reliance on such a sequence for the total synthesis of alliacolide, beginning with **10,** is certainly a viable possibility. Indeed, Kienzle[36] has used γ-allylation of a sterically biased enone sulfone (such as **10**) in carotenoid synthesis.

Scheme IV



a) n-BuLi; b) 1,3-dichloro-2-butene; c) 80% H_2SO_4, 0°C; d) NBS, CCl_3 Δ; e) LiCl, $CaCO_3$, DMF.

Table II. Alkylation Selectivities in **10**

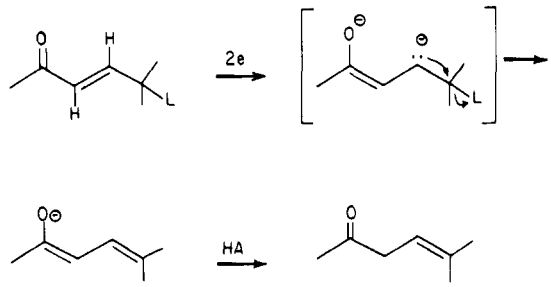


CH_3I	95 (13)	5
C_2H_5Br	80 (14)	20
$CH_2=CHCH_2Br$	85 (15)	15
$CH_3CH=CHCH_2-Br$	80	20
n-BuBr	80	20
$CH_2-CH(CH_2)_2Br$*	95	5
$(CH_3)_2CHI$#	~100	0
$N\equiv C(CH_2)_4Br$	85	15

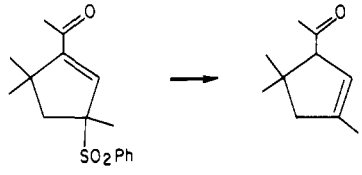
*Total yield ca. 50% in this experiment.

Using the K^+ salt of 10.

Finally, procedures for the removal of the γ-phenylsulfonyl group require some discussion. α,β-Unsaturated carbonyl compounds containing "good" leaving groups at the γ position are susceptible to dissolving metal reductive elimination,[37] with the resultant dienolate able to survive further reduction by means of appropriate quenching techniques. The desulfonylation of **2** with zinc in acetic acid to give 3-acetyl-1-methylcyclopentene, which was subsequently reconjugated to **4** (Scheme III), is one example of the above methodology. In

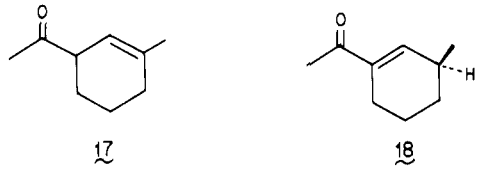


addition, ketone **13** was reductively deconjugated to **16** with lithium in liquid ammonia, as well as by zinc-acetic acid. In



13 16

a third variant of this approach, excess lithium dimethylcuprate effected smooth elimination[38] of the sulfone substituent in **6**, giving **17** initially and then **18** upon acidic equilibration.



17 18

Doubtlessly, additional means (including electrochemical) for reductive cleavage of γ-sulfonyl groups can be employed, depending on the specific compounds under investigation.

Discussion and Conclusion

It has been demonstrated that γ-(phenylsulfonyl) α,β-unsaturated ketones form resonance-stabilized anions that react with alkyl halides to give γ-alkylation products. However, the combined steric bulk of the sulfonyl group and α branching in the halide undergoing backside displacement results in increased amounts of α-attack as steric hindrance increases (Et > allyl > Me). When steric hindrance to α-attack is also significant (e.g., in **10**), a greater variety of halides undergo electrophilic bonding at the γ position of these weakly nucleophilic ions. It is not a simple matter to introduce γ-sulfonyl substituents into all α,β-unsaturated ketones, which makes the method less than optimal; fortunately, there are alternative modes[30,31] for assembling such γ-alkylation substrates, *including chloro olefin annelation of sulfone-containing* substrates.[35] The chemistry discussed herein is not the final solution to the γ-alkylation problem but it is a promising beginning.

Experimental Section

Melting points, taken in capillary tubes on a Mel-Temp apparatus, and boiling points are uncorrected. All carbanion experiments were conducted in nitrogen atmospheres. ^1H NMR spectra were recorded on Varian T-60 or JEOL MH-100 spectrometers using chloroform-*d* as solvent with tetramethylsilane as internal standard. Infrared spectra were obtained on a Perkin-Elmer Model 467 spectrometer, using neat liquids or Nujol mulls of crystalline solids. Ultraviolet spectra were obtained using a Perkin-Elmer 202 UV-visible spectrometer and mass spectra with a Perkin-Elmer Hitachi RMU-6E instrument. Microanalyses were performed by Atlantic Microlabs, Atlanta, Ga.

1-Acetyl-3-(phenylsulfonyl)cyclopentene (1). A mixture of 1-acetylcyclopentene (1.1 g, 10 mmol), *N*-bromosuccinimide (2.46 g, 15 mmol), and azoisobutyronitrile (5 mg) in 20 mL of carbon tetrachloride was irradiated with a 250-W long-wave UV lamp. After 0.5 h, the reaction flask was cooled, succinimide removed by filtration, and the filtrate washed with 10% aqueous sodium bisulfite. After drying over $MgSO_4$ and solvent evaporation, the crude bromo ketone was dissolved in 20 mL of *N,N*-dimethylformamide (DMF) in a 100-mL flask and cooled to 0 °C. Sodium benzenesulfinate (2.46 g, 15 mmol) was slowly added and the reaction mixture kept at 0 °C for 5 h, then quenched into 10% aqueous hydrochloric acid. The product was extracted into ether, which was washed with saturated aqueous $NaHCO_3$, dried over $MgSO_4$, and evaporated down, yielding 1.5 g of crude material. Fractional crystallization from 1:4 acetone–ether afforded 234 mg of **1**, mp 111–112 °C: ^1H NMR δ 2.3 (3 H, s), 2.4 (4 H, m), 4.47 (1 H, m), 6.48 (1 H, m) 7.5–7.9 (5 H, complex); IR (Nujol mull) ν_{max} 1672, 1313, 1167 cm^{-1}; UV (95% ethanol) λ_{max} 242 nm (ε 12 800); MS *m/e* 250 (M^+), 109, 93, 65. Anal. ($C_{13}H_{14}O_3S$) C, H.

1-Acetyl-3-(phenylsulfonyl)cyclohexene (5). Using the above procedure, 1-acetylcyclohexene (6.2 g, 50 mmol), *N*-bromosuccinimide (9.1 g, 51 mmol), and azoisobutyronitrile (60 mg) in 150 mL of carbon tetrachloride were stirred at 75 °C for 0.5 h, then worked up. The crude bromo ketone was combined with sodium benzenesulfinate (8.4 g, 50 mmol) in 150 mL of DMF and kept overnight at room temperature. After quenching into dilute hydrochloric acid and workup, there remained 9.0 g of oil, from which crystallization (ether) provided 6.64 g (43% yield) of pure **5**, mp 79.5–81 °C: ^1H NMR δ 1.4–2.5 (6 H, complex), 2.3 (3 H, s), 4.0 (1 H, m), 6.85 (1 H, m), 7.6–7.9 (5 H, complex); IR (Nujol mull) ν_{max} 1670, 1310, 1145 cm^{-1}. Anal. ($C_{18}H_{16}O_3S$) C, H.

General Alkylation Procedures. Methylation of 1-Acetyl-3-(phenylsulfonyl)cyclopentene (1 → 2). Varying amounts (ca. 25–500 mg, 0.1–2.0 mmol) of the keto sulfones **1, 5,** or **10** were dissolved in DMF and cooled to 0 °C and 1.01 equiv of sodium hydride was added. After the mixture was stirred under N_2 for 10 min, the alkyl halide (1.01 equiv) was added and the reaction mixture kept overnight, or less as specified. After the reaction mixture was quenched into 10% aqueous hydrochloric acid, products were extracted into ether and the latter was washed with saturated aqueous $NaHCO_3$ and dried over $MgSO_4$. Rotary evaporation gave the crude product, which was analyzed by IR and NMR to determine the ratio of α- to γ-alkylation product, as well as to search for O-alkylated products (usually not detected).

The α-/γ-alkyl ratio was determined in the crude product by integration (average of several curves) of the vinyl proton "singlets" (broadened by long-range allylic coupling) in the δ 6.3-6.8 region.

Using the above procedure, 500 mg of **1** in 8 mL of DMF gave 502 mg (95%) of crude product. NMR integration of the vinyl peaks at δ 6.4 (γ-methyl) and 6.67 (α-methyl) gave a ratio of 91:9. For α-alkylation product **3**: ^{1}H NMR δ 2.13 (s), 6.67 (br s); IR (film) ν_{max} 1708 cm^{-1}. Crystallization of the crude product gave pure **2**, mp 101-103 °C (ether): ^{1}H NMR δ 1.58 (3 H, s), 6.4 (1 H, 5, J = 1 Hz), 7.6-7.85 (5 H, complex); IR (Nujol mull) ν_{max} 1673, 1308, 1151 cm^{-1}; UV (95% ethanol) λ_{max} 242 nm (ε 10 000). Anal. ($C_{14}H_{16}O_3S$) C, H.

Numerous alkylations with other alkyl halides summarized in Table I were done using 25-100 mg of **1**, and product ratios determined by NMR; isolation of individual products was not attempted in those runs.

Preparation of 1-Acetyl-3-(phenylsulfonyl)-5,5-dimethylcyclopentene (10). A solution of phenyl prenyl sulfone[39] (42.1 g, 0.2 mol) in 300 mL of tetrahydrofuran (THF) was placed in a 1-L round-bottom flask, equipped with argon inlet, magnetic stirrer, and rubber septum inlet, then cooled to −75 °C. *n*-Butyllithium (122.5 mL of 2.04 M, 0.25 mol) was added dropwise during 1 h, with the temperature kept at −65 to −75 °C, followed by 104 mL of hexamethylphosphoramide (red color). 1,3-Dichloro-2-butene (26.2 g, 0.21 mol) was gradually added, with reaction temperature kept at −70 °C, and the mixture then allowed to warm to room temperature overnight. Quenching into 2 L of 10% aqueous HCl was followed by ether extraction, washing ($NaHCO_3$), drying ($MgSO_4$), and solvent evaporation to give oily diene **11** in 96% yield (57.2 g): ^{1}H NMR δ 1.17 (3 H, d, J = 1.5 Hz), 1.65 (3 H, d, J = 1.5 Hz), 2.03 (3 H, d, J = 1.5 Hz), 2.73 (2 H, m), 3.83 (1 H, t of d, J = 9, 4.5 Hz), 4.93 (1 H, m), 5.73 (1 H, m), 7.5-7.8 (5 H, complex); IR (film) ν_{max} 1660, 1302, 1146 cm^{-1}; MS *m/e* 298 (M^+), 157, 121, 105, 93, 77 (base peak). Anal. ($C_{15}H_{19}ClO_2S$) C, H.

Diene **11** (25 g, 0.085 mol) was added dropwise to a well-stirred solution of 263 mL of sulfuric acid and 87 mL of water at 15 °C. After 0.5 h more, the mixture was poured onto 1.2 kg of ice and extracted with methylene chloride (3 × 300 mL). The combined extracts were washed with saturated aqueous $NaHCO_3$, dried over $MgSO_4$, and evaporated to yield crude **12,** which was next chromatographed over alumina. Elution with 1:4 ethyl acetate-cyclohexane gave 19.4 g of light brown, oily **12** which afforded crystalline material, mp 69-70 °C (12 g, 50%), from ether at −75 °C. This was shown to be a cis-trans mixture by ^{1}H NMR: one isomer showed methyl singlets at δ 0.82 and 1.27, the other at 0.91 and 1.21 ppm. IR (film): ν_{max} 1706, 1313, 1155 cm^{-1}. MS: *m/e* 280 (M^+), 139, 95 (base peak). Anal. ($C_{15}H_{30}O_3S$) C, H.

A mixture of **12** (10 g, 0.036 mol), *N*-bromosuccinimide (7.2 g, 0.04 mol), and 250 mL of carbon tetrachloride in a 500-mL round-bottom flask, equipped with reflux condenser, was irradiated *without stirring* by three 250-W heat lamps positioned as closely as possible to the flask. After 10 min, the mixture was cooled, filtered, and washed with aqueous $NaHSO_3$, as before, then dried ($MgSO_4$) and evaporated. The crude bromo ketone, along with lithium chloride (2.5 g) and calcium carbonate (2.5 g), was placed in 120 mL of DMF and heated under argon at 110 °C for 1 h. After cooling, the reaction mixture was quenched into 10% aqueous HCl, extracted with ether (3 × 100 mL), and worked up in the conventional way, yielding 9.45 g (95%) of **10** as a pale yellow oil, which crystallized from ether, mp 132-135 °C: ^{1}H NMR δ 1.14, 1.17, 2.27 (three 3 H singlets), 6.48 (1 H, d, J = 2 Hz); IR (film) ν_{max} 1682, 1312, 1156 cm^{-1}; UV (95% ethanol) λ_{max} 237 nm.

γ-Alkylation Products from 10. The general alkylation procedure described for **1** was used in this series of runs.

A. With Methyl Iodide. Using the above procedure, 37 mg (0.13 mmol) of **10** and slight excesses of methyl iodide and sodium hydride in 1 mL of DMF gave 38 mg of crude product. The γ-/α-methylation ratio was 95/5, as determined by NMR integration of the relevant vinyl signals at δ 6.46 and 6.84. Crystallization from ether gave pure **13,** mp 117-119 °C: ^{1}H NMR δ 0.97 (3 H, s), 1.24 (3 H, s), 1.6 (3 H, s), 2.41 (3 H, s), 6.46 (1 H, s), 7.6-8.0 (5 H, complex); IR (Nujol mull) ν_{max} 1677, 1312, 1152 cm^{-1}; UV (95% ethanol) λ_{max} 240 nm (ε 12 400); MS *m/e* 220, 150, 135, 107 (base peak). Anal. ($C_{16}H_{20}O_3S$) C, H.

B. With Ethyl Bromide. 10 (69 mg, 25 mmol), along with slight excesses of sodium hydride and ethyl bromide in 1 mL of DMF, gave 67 mg of crude ethylation products. The γ/α ratio was 80/20, from NMR integration of vinyl signals at δ 6.34 and 7.00; the α-alkylation product gave a weak infrared carbonyl band at 1700 cm^{-1}. Crystallization from ether gave pure **14,** mp 129.5-130 °C: ^{1}H NMR δ 0.90 (3 H, s), 0.93 (3 H, t, J = 7.5 Hz), 1.21 (3 H, s), 1.65, 2.3 (4 H, complex), 2.3 (3 H, s), 6.34 (1 H, s), 7.6-7.9 (5 H, complex); IR (film) ν_{max} 1672, 1310, 1160 cm^{-1}; UV (95% ethanol) λ_{max} 241 nm (ε 21 500): MS *m/e* 164, 149, 121 (base peak). Anal. ($C_{17}H_{22}O_3S$) C, H.

C. With Allyl Bromide. A mixture of **10** (50 mg, 0.18 mmol) and slight excesses of allyl bromide and sodium hydride in 1 mL of DMF gave 54 mg of crude product. The γ/α ratio was determined to be 85/15 by integration of vinyl proton peaks at δ 6.37 and 6.96, and α-allylation product showed in the crude infrared spectrum at 1700 cm^{-1}. Crystallization from ether gave pure **15,** mp 85-85.5 °C: ^{1}H NMR δ 0.95 (3 H, s), 1.27 (3 H, s) 1.83 and 2.9 (2 H, AB quartet with J = 16 Hz), 2.23 (3 H, s), 5.19 (3 H, m), 6.37 (1 H, s), 7.6-7.9 (5 H, complex); IR (film) ν_{max} 1682, 1302, 1142 cm^{-1}. Anal. ($C_{18}H_{22}O_3S$) C, H.

Preparation of γ-(Phenylsulfonyl)tiglaldehyde (8). These experiments were performed by Mr. David A. Jeffrey.

A. To a warm solution (35 °C) of phenyl prenyl sulfone (11.2 g, 0.053 mol) in 100 mL of dioxane were added small portions of selenium dioxide (11.76 g, 0.106 mol). After 1.5 h at 80 °C, dilute hydrochloric acid was added and the deposited selenium removed by filtration through Celite. The filtrate was diluted with ether, washed with dilute hydrochloric acid, saturated $NaHCO_3$ solution, and saturated brine solution, dried over $MgSO_4$, and evaporated to a brown oil. Recrystallization from ether-pentane eventually gave **8**, mp 109-111 °C; ^{1}H NMR δ 1.48 (3 H, s), 4.13 (2 H, d, J = 7 Hz), 6.42 (1 H, t, J = 7 Hz, further long-range coupling, $J \sim 1$ Hz), 7.4-8.0 (5 H complex), 9.33 (1 H, s); IR (film) ν_{max} 1688, 1589, 1314, 1155 cm^{-1}; UV (95% ethanol) λ_{max} 236 nm (ε 10 400).

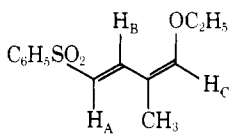
B. γ,γ-Dimethylallyl chloride (2.61 g, 0.025 mol) in 50 mL of dioxane was treated with selenium dioxide (5.55 g, 0.050 mol) and stirred at 70 °C for 0.5 h. Workup as above afforded 1.5 g of crude aldehyde, via Kugelrohr distillation, which was immediately combined with excess sodium benzenesulfinate in DMF. After the reaction mixture was kept overnight it was worked up in the usual manner to give 1.85 g (66%) of the sulfone aldehyde **8**, mp 110-112 °C, spectrally identical with the material from route A.

Alkylation of γ-(Phenylsulfonyl)tiglaldehyde (8). These experiments were performed by Mr. D. A. Jeffrey.

A. With Methyl Iodide. A solution of **8** (250 mg, 1.1 mmol) was reacted with slight excesses of sodium hydride and methyl iodide in DMF (3 mL) for 3 h, then worked up in the usual manner. The crude product was virtually pure γ-alkylate (**9**), and readily gave crystals, mp 94-96 °C (from ether-hexane): ^{1}H NMR δ 1.46 (3 H, s), 1.66 (3 H, d, J = 7 Hz), 4.23 (1 H, m), 6.27 (1 H, m), 7.4-7.8 (5 H, complex), 9.39 (1 H, s); IR (film) ν_{max} 1686, 1640, 1587, 1320, 1160 cm^{-1} Anal. ($C_{12}H_{12}SO_3$) C, H.

Confirmation of structure **9** was accomplished by changing the order of steps, beginning with phenyl prenyl sulfone. The sulfone (500 mg) was metalated in THF with 1 equiv of *n*-butyllithium (following the procedure described above for preparing **11**) and HMPA and then methyl iodide were added. After the mixture was stirred overnight, hydrolysis and workup gave 460 mg (85%) of oily methylation product (δ 1.43, d, J = 7 Hz, inter alia). Selenium dioxide oxidation of this material, as described for the preparation of **8**, afforded 175 mg (36%) of pure **9**, mp 94-95 °C, identical in all respects with the methylation product of **8**.

B. With Ethyl Bromide. When alkylation of **8** was attempted with ethyl bromide, in the same manner as with methyl iodide, the NMR spectrum of the crude product revealed ca. 50% recovered starting material and ca. 50% of O-alkylation product, the pertinent signals being indicated with the structure



H_a, H_b 6.0, 72 (d, J = 16 Hz)
H_c 6.6 (s)

Reductive Desulfonylation. A. A solution of **13** (292 mg, 1 mmol) in 3 mL of THF was added dropwise to lithium (139 mg, 20 mmol) dissolved in 100 mL of liquid ammonia. After 5 min, solid ammonium

chloride was added until the blue color was discharged. The ammonia was allowed to evaporate and the residue partitioned between water (100 mL) and ether (150 mL). Standard workup of the organic phase afforded 184 mg of 3-acetyl-1,4,4-trimethylcyclopentene (**16**) ($\nu_{>=0}$ 1709 cm^{-1} and vinyl proton resonance at δ 5.22) and 1-acetyl-3,5,5-trimethylcyclopentene ($\nu_{>=0}$ 1671 cm^{-1} and vinyl proton resonance at δ 6.42), alone with contaminating diphenyl disulfide (δ 7.25, complex).

B. A mixture of **13** (292 mg, 1 mmol), zinc powder (654 mg, 10 mmol), and acetic acid (10 mL) was stirred for 20 h at room temperature. After zinc was removed by filtration, the solution was diluted with water and extracted with ether. The latter was washed and dried and solvent removed to provide 142 mg of pure **16:** ^1H NMR δ 0.97 (3 H, s), 1.24 (3 H, s), 1.75 (3 H, d, J = 1 Hz), 2.07 (3 H, s), 3.19 (1 H, m), 5.22 (1 H, m); IR (film) ν_{max} 1709 cm^{-1}; MS *m/e* 152 (M^+), 109 (base peak) 43.

C. A solution of **6** (282 mg, 1 mmol) in 5 mL of ether was slowly added to lithium dimethylcuprate (5 mmol) freshly prepared from cuprous iodide (962 mg, 5 mmol) and methyllithium (6.82 mL of 1.48 M, 10 mmol) in 20 mL of ether. After the mixture had stood overnight, it was quenched into dilute ammonium hydroxide and worked up to provide 286 mg of crude product. Kugelrohr distillation (100 °C, 7 Torr) gave 92 mg of pure **17:** ^1H NMR δ 1.7 (3 H, m), 2.15 (3 H, s), 1.87 (6 H, m), 3.05 (1 H, m), 5.47 (1 H, m); IR (film) ν_{max} 1712 cm^{-1}. Compound **17** was kept for several hours in 10 mL of 95% ethanol containing 3 drops of concentrated HCl. Dilution and workup in the usual fashion gave 82 mg of ketone **18:** ^1H NMR δ 1.38 (3 H, d, J = 7 Hz), 1.7-2.2 (7 H, complex), 2.33 (3 H, s), 6.72 (1 H, br s); IR (film) ν_{max} 1688 cm^{-1}.

Acknowledgments. We are grateful to the National Science Foundation for support of this research. Dr. Joseph F. Bieron carried out the initial synthesis and methylation of **5.**

References and Notes

(1) House, H. O. "Modern Synthetic Reactions", 2nd ed.; W. A. Benjamin: New York, 1972; pp 492-628.
(2) ApSimon, J. "The Total Synthesis of Natural Products", Vol. I-III; Wiley-Interscience: New York, 1973.
(3) Waring, A. J. In "Comprehensive Organic Chemistry", Stoddart, J. F., Ed.; Pergamon Press: Elmsford, N.Y., 1979; Vol. I, pp 1017-1104.
(4) d'Angelo, J. *Tetrahedron* **1976,** *32,* 2979-2990.
(5) Seebach, D. *Angew Chem., Int. Ed. Engl.* **1979,** *18,* 239-258.
(6) Gompper, R.; Wagner, H-U. *Angew. Chem., Int. Ed. Engl.* **1976,** *15,* 321-333.
(7) Ando, M.; Buchi, G.; Ohmuma, T. *J. Am. Chem. Soc.* **1975,** *97,* 6880-6881.
(8) Schroepfer, G. J., Jr.; Parish, E. J.; Kandutsch, A. A. *J. Am. Chem. Soc.* **1977,** *99,* 5494-5496.
(9) Conia, J. M. *Rec. Chem. Prog.* **1963,** *24,* 43-62.
(10) (a) Bryson, T. A.; Gamill, R. B. *Tetrahedron Lett.* **1974,** 3963-3966. (b) Telschow, J. E.; Reusch, W. *J. Org. Chem.* **1975,** *40,* 862-865.
(11) Piers, E.; Zbozny, M.; Wigfield, D. C. *Can. J. Chem.* **1979,** *57,* 1064-1074.
(12) Grieco, P. A.; Oguri, T.; Wang, C-L. J.; Williams, E. *J. Org. Chem.* **1977,** *42,* 4113-4118.
(13) Stork, G.; Danheiser, R. L.; Ganem, B. *J. Am. Chem. Soc.* **1973,** *95,* 3414-3415.
(14) Wenkert, E.; Goodwin, T. E.; Ranu, B. C. *J. Org. Chem.* **1977,** *42,* 2137-2141.
(15) Trost, B. M.; Melvin, L. S. Jr. *J. Am. Chem. Soc.* **1976,** *98,* 1204-1212.
(16) Katzenellenbogen, J. A.; Crumrine, A. L. *J. Am. Chem. Soc.* **1976,** *98,* 4925-4935.
(17) Wu, A.; Snieckus, V. *Tetrahedron Lett.* **1975,** 2057-2060.
(18) Lansbury, P. T.; Erwin, R. W. *Tetrahedron Lett.* **1978,** 2675-2678.
(19) Johnson, W. S.; Dawson, M. I.; Ratcliffe, B. E. *J. Org. Chem.* **1977,** *42,* 153-158.
(20) (a) Herrmann, J. L.; Kieczykowski; Schlessinger, R. H. *Tetrahedron Lett.* **1973,** 2433-2436. (b) Rathke, M. W.; Sullivan, D. *Ibid.* **1972,** 4249-4252.
(21) White, J. D.; Sung, W. L. *J. Org. Chem.* **1974,** *39,* 2323-2328.
(22) Broaddus, C. D. *Acc. Chem. Res.* **1968,** *1,* 231-238.
(23) Cram, D. J. "Fundamentals of Carbanion Chemistry"; Academic Press: New York, 1965; pp 175-210.
(24) Truce, W. E.; Bannister, W. W.; Knospe, R. H. *J. Org. Chem.* **1962,** *27,* 2821-2828.
(25) Julia, M.; Arnould, D. *Bull. Soc. Chim. Fr.* **1973,** 743-750.
(26) Kende, A. S.; Constantinides, D.; Lee, S. J.; Liebeskind, L. *Tetrahedron Lett.* **1975,** 405-408.
(27) Lansbury, P. T.; Serelis, A. K., unpublished observations.
(28) Lansbury, P. T.; Erwin, R. W., unpublished observations.
(29) Markley, L. D. *J. Org. Chem.* **1973,** *38,* 3417-3418.
(30) Lam, C. N.; Mellor, J. N.; Picard, P.; Rawlins, M. F.; Stibbard, J. H. A. *Tetrahedron Lett.* **1978,** 4103-4106.
(31) Frydman, N.; Mazur, Y. *J. Am. Chem. Soc.* **1970,** *92,* 3202-3205.
(32) Erwin, R. W. Ph.D. Dissertation, State University of New York at Buffalo, 1979. Additional alkylation studies with **1** and **5** are described herein.
(33) Groenewegen, P.; Kallenberg, H.; van der Gen, A. *Tetrahedron Lett.* **1978,** 491-494.
(34) King, T. J.; Farrell, I. W.; Halsall, T. G.; Thaller, V. *J. Chem. Soc., Chem. Commun.* **1977,** 727-728.
(35) Lansbury, P. T. *Acc. Chem. Res.* **1972,** 311-320.
(36) Kienzle, F.; Minder, R. E. *Helv. Chim. Acta* **1976,** *59,* 439-452.
(37) Caine, D. *Org. React.* **1976,** *23,* 1-258.
(38) Ruden, R. A.; Litterer, W. E. *Tetrahedron Lett.* **1975,** 2043-2046.
(39) Martel, J.; Huynh, C. *Bull. Soc. Chim. Fr.* **1967,** 985.
(40) Sato, T.; Izumi, G.; Imamura, T. *J. Chem. Soc., Perkin Trans. 1* **1976,** 788-791.

Effect of pH on the Behavior of Duroquinone Triplets[1]

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Abstract: The triplet state of duroquinone has a pK_a of −0.1. The protonated form interacts with benzyl alcohol and chloride ions with rate constants which are about two orders of magnitude faster than those of the neutral form. Duroquinone triplets are quenched by a variety of inorganic anions, including OH^-, for which the rate constant is 1.5×10^9 M^{-1} s^{-1}. Quenching by amines and its pH dependence have also been examined.

Introduction

The photochemistry of carbonyl compounds in the presence of potential electron donors has been the subject of numerous studies.[2,3] Several of these studies have utilized aqueous solvents,[4-8] and some have investigated the effect of acid-base equilibria of the substrates on their reactivity,[9] but the examination of the effect of pH on the behavior of excited carbonyls has been rather uncommon.[10-13] In particular, duroquinone (DQ) has been the subject of a few studies which illustrate the strong oxidizing character of its triplet state,[4,7,14-18] a property which is shared by other quinone triplets. However, the acid-base properties of the duroquinone triplet have received no attention.

In this paper we report results on the behavior of duroquinone triplets in the range of pH 12 to H_0 − 2. The wide variations observed in these processes reflect the reactivity of the triplet toward hydroxide ions, the acid-base properties of some substrates (e.g., amines), and the acid-base equilibrium in the triplet manifold of duroquinone.

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