Solvolyses of Benzo[7,8]bicyclo[4.2.1]nonen-9(*exo*)-yl p-Bromobenzenesulfonate and Its Unsaturated Derivatives[1,2]

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Reduction of the carbonyl function in benzobicyclo[4.2.1]nona-2,4,7-trien-9-one (7) gave exclusively the corresponding exo trienol 5-OH, which was saturated to obtain the titled alcohol 4-OH. The rate of solvolysis of the brosylate 4-OBs together with the reported data on the other compounds gave the relative reactivities of benzobicyclo[2.1.1]hexen-5(*exo*)-yl, benzobicyclo[2.2.1]hepten-7(*anti*)-yl, benzobicyclo[3.2.1]octen-8(*exo*)-yl, and 4-OBs as 32, 1, 4.8 × 10⁻³, and 1.2 × 10⁻⁵, respectively. The hydrolysis in aqueous diglyme and acetolysis of 4-OBs produce olefins and alcohols. The alcohol fraction was a mixture of the retained 4-OH and the inverted alcohol 8-OH. In contrast, the alcohol fraction from trifluoroacetolysis consisted of 4-OH only. The hydrolysis of 5-OBs in 60% aqueous diglyme at 190° was found to proceed 6.7 × 10⁻² times more slowly than that of 4-OBs. The results from 4-OBs are interpreted in terms of competing aryl assistance and solvent assistance.

We have reported that the relative rates of acetolysis of benzobicyclo[2.1.1]hexen-5(*exo*)-yl (1,3-methanoindan-2(*exo*)-yl) arenesulfonate (1), benzobicyclo[2.2.1]-hepten-7(*anti*)-yl (benzonorbornen-9(*anti*)-yl) arene-sulfonate (2), and benzo[6,7]bicyclo[3.2.1]octen-8-(*exo*)-yl arenesulfonate (3) are 32, 1, and 0.0026 (55°),
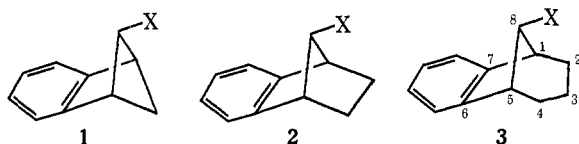
respectively, and that all these reactions produce the corresponding acetates with complete retention of configuration in quantitative yields.[3] Bond angles at the reaction sites of the arenesulfonates are estimated to be approximately 83° for 1, 96° for 2, and 101° for 3.[3–5] Consequently, the relative solvolysis rates decrease with increasing bond angles. This trend has been interpreted by the view that, if in compounds of this series the bond-angle effect accompanied by rehybridization of the reacting carbon atom from sp³ to sp² exists, it must be relatively unimportant and be overwhelmed by the aryl participation effect. This paper describes a determination of the rate and product formed in solvolysis of the next homolog, benzo[7,8]bicyclo[4.2.1]-nonen-9(*exo*)-yl brosylate (4-OBs). The solvolysis rate of the tetradehydro derivative 5-OBs has also been
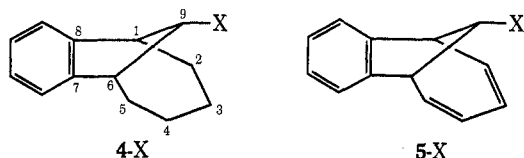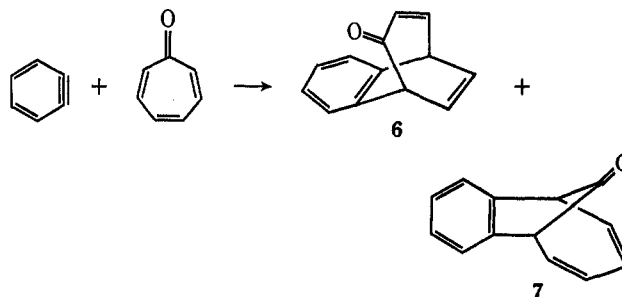

X = OH, OBs, or OAc

investigated in order to determine the influence of π electrons such as the four in this compound toward the developing cationic center.
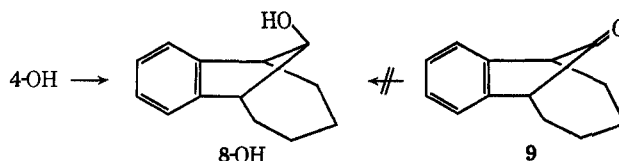
Results

Although the addition reaction of benzyne to tropone mainly produces benzo[6,7]bicyclo[3.2.2]nona-3,6,8-trien-2-one (6),[6] benzo[7,8]bicyclo[4.2.1]nona-2,4,7-trien-9-one (7) was isolated as a minor product and

characterized as a 1,6 cycloaddition product.[7] It seemed to us that this one-step synthesis of 7, despite the unsatisfactory yield, was most convenient for the preparations of 4 and 5. Meerwein–Ponndorf reduction of 7 with aluminum isopropoxide in 2-propanol gave a single alcohol (5-OH) as crystals, which was converted to the saturated alcohol (4-OH) by uptake of 2 molar equiv of hydrogen in methanol with palladium-on-carbon catalysis. The exo configuration of the hydroxyl groups in 5-OH and 4-OH was established by the presence of an infrared hydroxyl band associated with the unsaturation in 5-OH and its absence in 4-OH. Attempts to prepare the endo epimer of 5-OH by reduction of 7 or by epimerization of 5-OH have failed. However, the endo epimer of 4-OH (8-OH) was obtained by treatment of 4-OH with aluminum isopropoxide in xylene containing a trace of acetone (equilibration) and also by the solvolysis of 4-OBs but not by reduction of the corresponding ketone 9 (obtainable by

oxidation of 4-OH or 8-OH) by methods such as the Meerwein–Ponndorf, sodium metal in 2-propanol, or

(1) The numbering is shown in the illustrations.

(2) Compounds in which the substituent on the aliphatic ring is directed toward the benzene ring are defined as endo; those in which the substituent is directed away from the benzene ring are defined as exo.

(3) Y. Hata and H. Tanida, *J. Amer. Chem. Soc.*, **91**, 1170 (1969).

(4) Y. Tsukuda, T. Sato, M. Shiro, and H. Koyama, *J. Chem. Soc. B*, 1166 (1969).

(5) H. Koyama and K. Okada, *ibid.*, 940 (1969).

(6) J. Ciabatoni, J. E. Crowley, and A. S. Kende, *J. Amer. Chem. Soc.*, **89**, 2778 (1967).

(7) T. Miwa, M. Kato, and T. Tamano, *Tetrahedron Lett.*, 1761 (1969).

TABLE I

SOLVOLYSIS RATES OF *exo*-BENZOBICYCLO[*n*.2.1]ALKENYL DERIVATIVES

Compd[a]	Solvent	Temp, °C	k, sec^{-1}	$\Delta H^{\ddagger}$, kcal	$\Delta S^{\ddagger}$, cal/deg	Relative acetolysis rate
4-OBs (n = 4)	60% diglyme	190.0	2.32×10^{-4}			
		170.0	4.43×10^{-5}			
		77.6	1.81×10^{-9} [b]	33.1	−4.6	1.2×10^{-5} [c]
	CF_3COOH	120.0	2.73×10^{-4}			
		95.0	2.32×10^{-5}	27.6	−5.1	
5-OBs (n = 4, $\Delta^{2,3,4,5}$)	60% diglyme	190.0	1.55×10^{-5}			
2-Indanyl OBs	60% diglyme	80.0	1.35×10^{-3}			
		50.0	7.10×10^{-5}			
		77.6	1.09×10^{-3} [b]	21.6	−10.9	
	CH_3COOH	77.6	1.10×10^{-4} [d]	25.6	−3.9	7.4
3-OBs (n = 3)	CH_3COOH	77.6	7.14×10^{-8} [e]	32.0	−0.2	4.8×10^{-3}
2-OBs (n = 2)	CH_3COOH	77.6	1.49×10^{-5} [f]			1
1-OBs (n = 1)						32

[a] The concentrations of brosylates were 0.02 *M* in the hydrolyses and 0.3 *M* in the trifluoroacetolyses. [b] Calculated by Arrhenius plots. [c] Calculated using the rate ratio of 2-indanyl brosylate in CH_3COOH and 60% diglyme (see Discussion). [d] Calculated by Arrhenius plots of the data of H. Tanida, Y. Hata, S. Ikegami, and H. Ishitobi, *J. Amer. Chem. Soc.*, **89**, 2928 (1967). [e] Calculated by Arrhenius plots of the data in ref 3. [f] Reference 9.

sodium borohydride in methanol reductions. The alcohols 4-OH and 5-OH were esterified by *p*-bromobenzenesulfonyl chloride in pyridine and used for solvolyses.

Rates.—The solvent used for the hydrolyses of 4-OBs, 5-OBs, and, as a model compound for comparison, 2-indanyl brosylate, was prepared by mixing six parts of diglyme and four parts of water at 25° and adding 1.1 equiv of sodium acetate. The sodium acetate is consumed by the *p*-bromobenzenesulfonic acid liberated during the reaction, so that the rate can be determined by titrating the remaining sodium acetate at intervals with dilute hydrochloric acid. The trifluoroacetolysis of 4-OBs was carried out in anhydrous trifluoroacetic acid containing an equivalent of sodium trifluoroacetate and the rate determined by monitoring the nmr signal of the C-9 (endo) proton; the internal standard for integration was the aromatic protons.[8] Good first-order kinetics were observed in all runs and theoretical infinity titers were obtained. Rate constants thus obtained are summarized in Table I, together with the derived activation parameters. Acetolysis rates of some other compounds relevant to the discussion are also listed.

Products from 4-OBs.—In order to investigate the products formed, the hydrolysis of 4-OBs in 60% aqueous diglyme was carried out at 190° under the same conditions used for rate determination. The products found consisted of a mixture of hydrocarbons (two predominant peaks by capillary vpc) in 56% yield and a mixture of 4-OH with retention of configuration and 8-OH with inversion of configuration in 44% yield. Both the alcohols were transformed into an identical ketone (9)[7] by oxidation with chromic anhydride in pyridine, proving that they are epimers. Structures of the hydrocarbons were not established. No appreciable amount of rearranged alcohol was observed. The ratios of 4-OH to 8-OH varied according to the solvent used for the reaction, as summarized in Table II. Products from the acetolysis were of the same kind, while the trifluoroacetolysis did not give the inverted 8-OH.

TABLE II

COMPOSITION OF ALCOHOLS FROM SOLVOLYSES OF 4-OBs

Conditions[a]	Retention, %	Inversion, %
1	60	40
2	58	42
3	45	55
4	54	46
5	100	0

[a] Conditions: (1) in 60% aqueous diglyme containing 1 equiv of CH_3COONa at 190° for 8 hr; (2) in 60% aqueous diglyme containing 1 equiv of CH_3COONa at 170° for 17 hr; (3) in 80% aqueous diglyme containing 1 equiv of CH_3COONa at 190° for 89 hr; (4) in acetic acid containing 1 equiv of CH_3COONa at 190° for 17 hr; (5) in trifluoroacetic acid at 150° for 17 hr.

Discussion

The acetolysis rate *vs.* the hydrolysis rate at 77.6° in 60% aqueous diglyme of the model compound, 2-indanyl brosylate, gave the factor of 0.101. Using this factor, the acetolysis rate of 4-OBs is estimated and compared with those of 1, 2, and 3-OBs, as presented in Table I. In these bicyclo[*n*.2.1]brosylates, the bond angles at the reaction centers increase as the aliphatic "*n*" bridge becomes larger, as mentioned in the introduction. Inspection of a Fieser-Dreiding molecular model gives approximately 105° for the angle in 4-OBs. Thus, 1-OBs, with the smallest angle, solvolyzes with the fastest rate, 32 times as fast as 2-OBs and 4-OBs, having the largest angle, reacts with the slowest rate, 1.2×10^{-5} times that of 2-OBs. The acetolyses of 1-OTs, 2-OTs, and 3-OBs proceed with the formation of corresponding acetates with complete retention of configuration in quantitative yields.[3,9] Formation of an inverted product was now found in the acetolysis of 4-OBs as well as in the hydrolysis in aqueous diglyme. The relative yield of the inverted product increases with increasing water content of the diglyme. On the other hand, when trifluoroacetic acid which has high acidity and poor nucleophilicity was employed, there is no inverted product formation. These results can be accommodated if we consider that the acetolyses of 1-OTs, 2-OBs, and 3-OBs proceed entirely through an aryl-assisted pathway, while the

(8) A similar technique was used in H. Tanida, T. Irie, and T. Tsushima, *J. Amer. Chem. Soc.*, **92**, 3404 (1970).

(9) H. Tanida, T. Tsuji, and H. Ishitobi, *ibid.*, **86**, 4904 (1964).

solvolysis of 4-OBs proceeds with competing aryl assistance and solvent assistance.[8,10] The retention of configuration in products is a result of aryl assistance and the inversion of configuration is one of solvent assistance. However, neither kind of assistance in 4-OBs is strong enough to prevent "leakage," so that the leakage would lead to the formation of olefins. A general MO treatment of the interaction between the benzene π electrons and the developing p orbital at
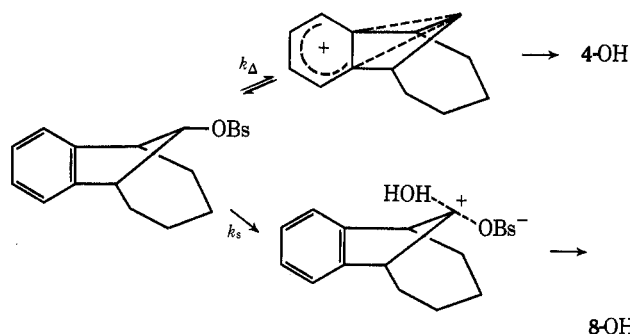
the reaction site, as introduced in a previous paper,[3] indicates for 4-OBs the least ability of the benzene to participate. Solvent assistance, or any reaction of S_N2 type in character, requires an approach from the backside of the leaving group. The Fieser–Dreiding molecular models indicate that, as the number of carbon atoms (n) making the methylene bridge in the present benzobicyclo[n.2.1]alkenyl derivatives increases, the distance between the reacting carbon and the juncture carbons of the aromatic and aliphatic parts becomes greater and the five-membered ring consisting of these three carbons and the two bridgehead carbons becomes flatter, resulting in a decrease of the shielding of the back side by benzene π electrons. Therefore, the facility of such a back-side approach of solvent should be greater for 4-OBs than for the other brosylates. The relative solvolytic reactivities obtained are an apparent reflection of magnitude of the aryl participation but do not disapprove potential importance of angle strain effects. Even in the case of 4-OBs, when trifluoroacetic acid which enhances aryl assistance[11] was used, the aryl-assisted process may be predominant, because inverted product was not found and because the yield of hydrocarbons was found to be less than that from the hydrolysis.

The tetradehydro 5-OBs is hydrolyzed 6.7×10^{-2} times (190°, 60% diglyme) more slowly than 4-OBs. Introduction of the two double bonds would depress the rate inductively and cause a steric influence on the rate. It is difficult to conclude whether or not these effects are sufficient to account for the rate depression of such moderate magnitude.[12] An impor-

(10) For the terminology and related discussions, see (a) S. Winstein, E. Allred, R. Heck, and R. Glick, *Tetrahedron*, **3**, 1 (1958); (b) C. J. Lancelot and P. v. R. Schleyer, *J. Amer. Chem. Soc.*, **91**, 4291 (1969), and the subsequent three communications.

(11) J. E. Nordlander and W. G. Deadman, *ibid.*, **90**, 1590 (1968).

(12) Treatment of **7** with sodium metal in 2-propanol gave the two dihydro alcohols **10-OH** and **11-OH** besides **5-OH**. Samples of **10-OH** and

tant clue would be obtained from the hydrolysis rate of the endo isomer of 5-OBs and the thus-derivable exo:endo rate ratio. If either isomer of the 5 system forms an antiaromatic bishomocyclopentadienyl cation (12), one should observe a rate depression too
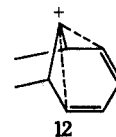
great to be accounted for by steric and inductive effects. However, we have not yet succeeded in the synthesis of the endo compound.

Experimental Section

Melting points were taken by capillary and are corrected. Infrared spectra were taken with a Nippon Bunko DS-201-B or DS-402-G spectrometer and nmr spectra with a Varian A-60A.

Benzobicyclo[4.2.1]nona-2,4,7-trien-9(exo)-ol (5-OH).—A solution of 53 mg of benzobicyclo[4.2.1]nona-2,4,7-trien-9-one (7)[7] and 71.3 mg of aluminum isopropoxide in 5 ml of 2-propanol was refluxed for 16.5 hr. The reaction mixture was poured into cold water, neutralized with dilute sulfuric acid, and then extracted with ether. The ether solution was washed with water saturated with sodium chloride, dried over sodium sulfate, and evaporated to leave 46 mg of 5-OH: mp 73.5–74.5°; homogeneous on vpc; nmr (CCl₄) δ ~3.7 (m, 2, bridgeheads), 4.63 (broad t, 1, C_9 H), ~5.9 (m, 4, vinyl), and 7.05 (s, 4, aromatic); ir (CCl₄) 3565 cm⁻¹ (OH associated with double bonds).

The brosylate 5-OBs had mp 142.5–143°.

Anal. Calcd for $C_{19}H_{15}O_3SBr$: C, 56.58; H, 3.75. Found: C, 56.77; H, 3.77.

Benzobicyclo[4.2.1]nonen-9(exo)-ol (4-OH).—Catalytic reduction of 5-OH over palladium on carbon in methanol ceased with the uptake of 2 molar equiv of hydrogen. The work-up gave 4-OH: mp 90.5–91.5°; nmr (CDCl₃) δ 1.0–2.2 (8, tetamethylene bridge), 3.3 (m, 2, bridgehead), 4.72 (t, 1, C_9 H), and 7.18 (4, aromatic); ir (CCl₄) 3631 cm⁻¹ (free OH).

Anal. Calcd for $C_{13}H_{16}O$: C, 82.93; H, 8.57. Found: C, 83.16; H, 8.52.

The brosylate 4-OBs had mp 139–139.5°.

Anal. Calcd for $C_{19}H_{19}O_3SBr$: C, 56.02; H, 4.70. Found: C, 56.14; H, 4.80.

Benzobicyclo[4.2.1]nonen-9(endo)-ol (8-OH).—A solution of 23 mg of 4-OH, 24.9 mg of aluminum isopropoxide, and a trace of acetone in 2 ml of o-xylene was heated in an ampoule at 120° for 5 days. Analysis of the reaction mixture by vpc indicated an approximately 1:1 mixture of 8-OH and 4-OH as well as minor amounts of benzobicyclo[4.2.1]nonen-9-one (9).[7] A pure sample of 8-OH, mp 107.5–108°, was isolated from the mixture by thin layer chromatography [the absorbent was silica gel G (E. Merck Co.) and the solvent was a 1:1 mixture of petroleum ether and ether]: nmr (CDCl₃) δ 1.0–2.1 (8, tetramethylene bridge), 3.27 (split q, 2, bridgehead), 4.27 (s, 1, C_9 H), and 7.20 (4, aromatic); ir (CCl₄) 3591 (OH associated with benzene), 3621 cm⁻¹ (free OH).
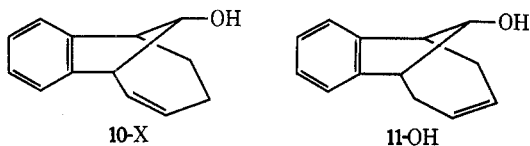
Anal. Calcd for $C_{13}H_{16}O$: C, 82.93; H, 8.57. Found: C, 82.87; H, 8.67.

Kinetic Measurements.—The hydrolysis solvent was prepared by mixing six parts of diglyme and four parts of water at 25° and adding 1.1 equiv of sodium acetate. The brosylate was dissolved and its concentration adjusted to 0.02 M. Aliquots, usually eight 2-ml portions of a reaction solution, were pipetted at constant temperature from the flask into ampoules. The sealed ampoules were brought to the reaction temperature, removed at

11-OH isolated by preparative vpc had a purity sufficient for nmr analyses but not for satisfactory elementary analyses. The brosylates, 10-OBs and 11-OBs, were prepared from these samples and hydrolyzed at 190° in the 60% aqueous diglyme. The reactivities relative to that of 4-OBs were roughly determined as 0.7 for 10-OBs and 0.8 for 11-OBs. Judging from these small effects due to the introduction of one double bond, it is unlikely that the inductive effect of two double bonds in 5-OBs is of major contribution to the factor of 6.7×10^{-2}.

10-X   11-OH

appropriate intervals of time, and run into 20 ml of cold dry acetone, and remaining sodium acetate was titrated with 0.004 N hydrochloric acid using a Metrohm potentiograph E 336 A. Plots of log $(A_\infty - A_t)$ vs. time, where A_∞ and A_t are titers at infinity and at the given times, respectively, were uniformly linear. The slopes multiplied by -2.303 gave the pseudo-first-order rate coefficients.

Solvolysis Products from 4-OBs.—The solvents and conditions used are listed in Table II. The concentration of 4-OBs was the same as that used for the rate measurements. The ratios of retained 4-OH and inverted 8-OH in Table II were determined by vpc analysis of the reaction mixture on a Hitachi gas chromatograph Model K-53 equipped with a hydrogen flame ionization detector and a UCON R-15 capillary column; the temperature of the column was 140° and carrier gas was helium at 2 kg/cm²

pressure. The products from trifluoroacetolysis were hydrolyzed by 50% aqueous methanol containing sodium carbonate and then analyzed by vpc.

Solvent was evaporated from the hydrolysis mixture under a reduced pressure and the residue was dissolved in ether. The ether solution was washed with aqueous sodium carbonate, dried, and evaporated. Treatment of the residue by thin layer chromatography as described above gave pure samples of 4-OH and 8-OH besides a mixture of hydrocarbons.

The Hydrolysis of 7,7-Dichlorobicyclo[3.2.0]hept-2-en-6-one[1]

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Tropolone is obtained in good yield by the sodium acetate–water–acetic acid hydrolysis of 7,7-dichlorobicyclo-[3.2.0]hept-2-en-6-one, the cycloadduct of dichloroketene and cyclopentadiene. Hydrolysis in aqueous sodium carbonate proceeds mainly with cleavage of the cyclobutanone ring, giving 1-formylcyclopentene-5-carboxylic acid, which is readily oxidized to cyclopentene-1,5-dicarboxylic acid. Structure assignments among the isomeric cyclopentenedicarboxylic acids were revised and the unreported cyclopentene-1,4-dicarboxylic acid was prepared. An improved procedure for the synthesis of 4,5-benzotropolone from the corresponding indene adduct is included.

Dichloroketene-based chemistry became the subject of extensive literature[3] following the preliminary report from this laboratory of an *in situ* generation and capture with reactive olefins to yield 2 + 2 cycloadducts. As a novel method of forming cyclobutanones it has already found considerable synthetic utility.[3g,l-o]

The initial experiments were carried out with cyclopentadiene leading to subject cycloadduct **1** which proved to be an intermediate precursor of tropolone **2**.[1a]
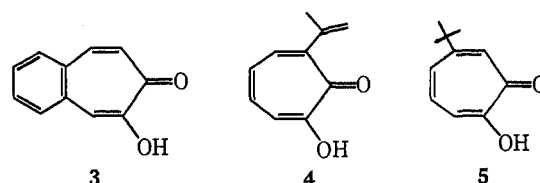

1   **2**
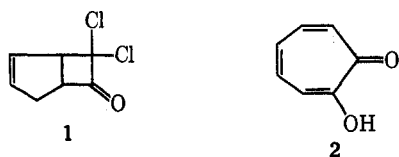
The general approach has been extended by several investigators to substituted tropolones **3-5** via the corresponding 2 + 2 cycloaddition with indene,[3d,l,o] 6,6-dimethylfulvene,[4] and 1-*tert*-butylcyclopentadiene.[5]

3   **4**   **5**

From a synthetic viewpoint, dichlorobicycloheptenone (**1**) has proven to be a useful intermediate. Reductive dechlorination provides the best source of bicyclo[3.2.0]hept-2-en-6-one, not easily accessible from ketene and cyclopentadiene.[6] Brook showed the sodium borohydride reduction of **1** to result in a mixture of endo and exo alcohols, precursors of stereoisomeric carboxaldehydes and carboxylic acids of the [3.1.0] ring system.[7] The reaction of **1** with sodium methoxide resulted in the cleavage of the cyclobutanone ring to give an isomer of **6**.[3a] Lactone **7** has recently been

6   **7**

isolated in the triethylamine-catalyzed hydrolysis of **1** in aqueous acetone.[5] This paper deals with the unusual course of solvolytic reactions observed with **1**, leading to tropolone on one hand and cyclopentene derivatives on the other.
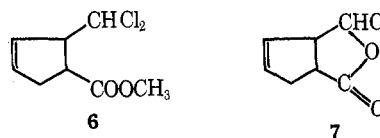
(1) For preliminary communications of this work, see (a) H. C. Stevens, D. A. Reich, D. R. Brandt, K. R. Fountain, and E. J. Gaughan, *J. Amer. Chem. Soc.*, **87**, 5257 (1965); (b) H. C. Stevens and G. M. Trenta, *Chem. Commun.*, 1407 (1970).

(2) To whom inquiries should be addressed.

(3) (a) L. Ghosez, R. Montaigne, and P. Mollet, *Tetrahedron Lett.*, 135 (1966); (b) W. T. Brady, H. G. Liddell, and W. L. Vaughn, *J. Org. Chem.*, **31**, 626 (1966); (c) D. Borrmann and R. Wegler, *Chem. Ber.*, **99**, 1245 (1966); **102**, 64 (1969); (d) R. W. Turner and T. Seden, *Chem. Commun.*, 399 (1966) (since no experimental details are given and low yields are indicated, a preparation of 4,5-benzotropolone is included in this paper); (e) R. Hull, *J. Chem. Soc.*, 1154 (1967); (f) J. Ciabottini and H. W. Anderson, *Tetrahedron Lett.*, 3377 (1967); (g) W. T. Brady and O. H. Waters, *J. Org. Chem.*, **32**, 3703 (1967); (h) R. Montaigne and L. Ghosez, *Angew. Chem.*, **80**, 194 (1968); (i) L. Ghosez, R. Montaigne, H. Vanlierde, and F. Dumay, *Angew. Chem., Int. Ed. Engl.*, **7**, 643 (1968); (j) J. M. Lavanish, *Tetrahedron Lett.*, 6003 (1968); (k) H. Knoche, *Justus Liebigs Ann. Chem.*, **722**, 232 (1969); (l) R. E. Harmon and T. R. Potts, *J. Org. Chem.*, **34**, 2792 (1969); (m) V. R. Fletcher and A. Hassner, *Tetrahedron Lett.*, 1071, 5053 (1970); (n) E. J. Corey, Z. Arnold, and J. Hutton, *ibid.*, 307 (1970); (o) L. Ghosez, private communication.

(4) T. Asao, T. Machiguchi, T. Kitamura, and Y. Kitahara, *Chem. Commun.*, 89 (1970).

(5) P. Bartlett and T. Ando, *J. Amer. Chem. Soc.*, **92**, 7518 (1970).

(6) M. Rey, J. A. Huber, and A. S. Dreiding, *Tetrahedron Lett.*, 3583 (1968).

(7) P. R. Brook, *Chem. Commun.*, 565 (1968).