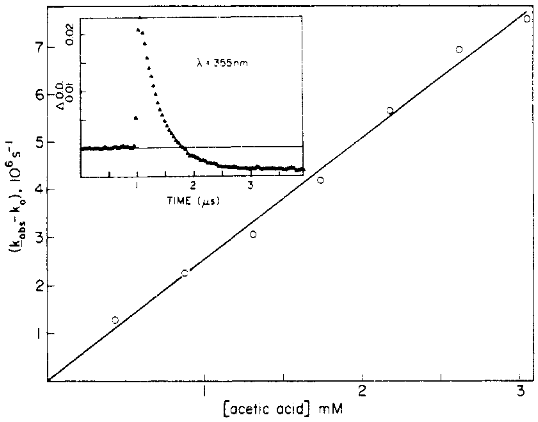
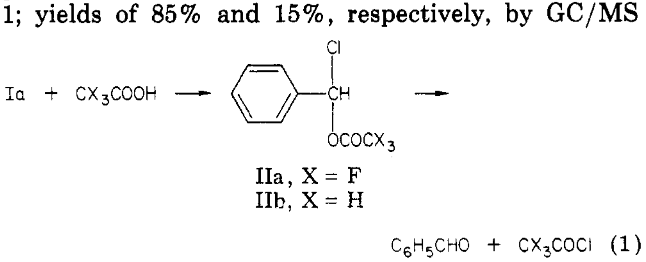


Figure 1. Quenching of Ib by acetic acid in acetonitrile at 300 K and (insert) a typical decay trace illustrating the decay of the carbene and bleaching of its precursor.

Photolysis (λ > 300 nm) of phenylchlorodiazirine (0.35 M) and trifluoroacetic acid (0.32 M) in isooctane solvent gave IIa as the major product with some benzaldehyde (eq 1; yields of 85% and 15%, respectively, by GC/MS analysis). A similar experiment with acetic acid gave a product which decomposed thermally to give benzaldehyde and was presumed to be IIb. Similar experiments with (*p*-methoxyphenyl)chlorodiazirine did not lead to significant product formation since highly colored material was quickly formed which screened the samples from further photolysis. From the above results we conclude that Ia reacts with acetic and trifluoroacetic acids to give the expected insertion products, and we presume that Ib behaves in a similar way (eq 1).



Ia + CX_3COOH →

IIa, X = F
IIb, X = H

→ $C_6H_5CHO + CX_3COCl$ (1)

Carbenes Ia and Ib could be easily monitored at 326 and 355 nm, respectively. The unsubstituted carbene, Ia, has been established to have a singlet ground state,[12] which is responsible for the signals observed in the laser flash experiments. Carbene Ib was investigated by using the same experimental criteria, and since it showed essentially the same pattern of behavior, it is therefore also believed to have a singlet ground state.[17]

The transient absorptions due to Ia and Ib were quenched when acetic acid was added to the samples used in the laser flash photolysis experiments. When the observed pseudo-first-order rate constants, k_{obsd}, for the decay of transients Ia and Ib were plotted against acetic acid concentration, linear plots of high quality ($r > 0.985$) were obtained (eq 2 and Figure 1), where k_q are the rate constants for reaction of the carbenes with acetic acid. It was found that k_o, the rate constant for carbene decay in the absence of acid, was negligible compared to $k_q[CH_3COOH]$.[18]

$$k_{obsd} = k_o + k_q[CH_3COOH] \qquad (2)$$

Table I. Rate Constants for Some Reactions of Singlet Arylchlorocarbenes at 300 K

carbene	quencher	solvent	k_q, M^{-1} s^{-1}
Ia	acetic acid	acetonitrile	$(1.78 \pm 0.36) \times 10^9$
Ia	acetic acid	isooctane	$(3.1 \pm 0.6) \times 10^9$
Ib	acetic acid	acetonitrile	$(2.16 \pm 0.10) \times 10^9$
Ib	acetic acid	isooctane	$(5.1 \pm 1.2) \times 10^9$
Ia	trifluoroacetic acid	acetonitrile	$(2.40 \pm 0.12) \times 10^9$
Ia	ethyl acetate	acetonitrile	$<2 \times 10^6$
Ia	dimethylbut-2-ene	acetonitrile	$(1.95 \pm 0.28) \times 10^8$
Ia[a]	dimethylbut-2-ene	isooctane	1.3×10^8
Ib	dimethylbut-2-ene	acetonitrile	$(2.04 \pm 0.10) \times 10^8$

[a] From ref 12.

Similar studies were carried out with trifluoroacetic acid; the rate constants for all these reactions are summarized in Table I. In all cases plots using eq 2 gave straight lines. This contrasts with experiments in which *tert*-butyl alcohol or methanol was used as a quencher, where similar plots showed pronounced curvature due to changes in hydrogen bonding equilibria.[19] Indeed, at the concentrations of acetic acid used in these experiments, the ratio of monomer to dimer in solution was >10.[20,21]

The rate constants for the reactions of Ia and Ib with acids are among the fastest known carbene–molecule reactions. They are similar to those for the O–H insertion reactions of Ia and Ib into methanol oligomers for which $k_q \approx 3 \times 10^9$ M^{-1} s^{-1} (isooctane solvent) and are much faster than that for insertion of Ib into methanol monomer for which $k_q \approx 2 \times 10^7$ M^{-1} s^{-1}.[19]

In order to set the results obtained for quenching by acids into the context of other reactions of carbenes Ia and Ib, we have measured rate constants for the reactions of these carbenes with dimethylbut-2-ene and ethyl acetate. The results are given in Table I. Clearly, the reactions with acids are more facile than those with olefins, the insensitivity toward acid strength probably reflecting an early transition state. Moreover, this high reactivity must be associated with the lability of the O–H bonds since ethyl acetate was not effective as a quencher.

Registry No. Ia, 19807-41-1; Ib, 82849-42-1; trifluoroacetic acid, 76-05-1; acetic acid, 64-19-7; ethyl acetate, 141-78-6; dimethylbut-2-ene, 563-79-1; phenylchlorodiazirine, 4660-46-2; (*p*-methoxyphenyl)chlorodiazirine, 4222-26-8.

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(17) We are grateful to Drs. M. S. Platz and K. F. Preston for carrying out the EPR experiments.

(18) In the absence of quenchers both carbenes underwent predominantly second-order decay and gave rise to highly colored products. These products were strongly absorbing in the UV region, such that only a few decay traces could be obtained from a single sample.

(19) Griller, D.; Liu, M. T. H.; Scaiano, J. C. *J. Am. Chem. Soc.* **1982**, *104*, 5549–5551.

(20) Nagai, Y.; Simamura, O. *Bull. Chem. Soc. Jpn.* **1962**, *35*, 132.

(21) Based on data in benzene solvent; even less dimer is expected in acetonitrile.

Aqueous Polar Aprotic Solvents. Efficient Sources of Nucleophilic Oxygen

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Received August 30, 1982

The replacement of various functional groups with oxygenated moieties is of considerable importance in synthetic endeavors and has led, over the years, to the development of several reagents that serve as nucleophilic sources of oxygen, including hydroxide,[1] peracids,[2] su-

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(1) See: March, J. "Advanced Organic Chemistry"; McGraw-Hill: New York, 1977; p 341.

Table I. Displacement of Alkyl Halides and Tosylates with Water in Polar Aprotic Solvents

entry	compound	solvent[a] (time, h)	product(s)	yield,[b] %
1	1-$C_{12}H_{25}I$	HMPA (2.5)	1-$C_{12}H_{25}OH$	94
2		NMP (5.5)		69
3	1-$C_8H_{17}I$	HMPA (2.5)	1-$C_8H_{17}OH$	92
4		NMP (5.5)		78
5	1-$C_{12}H_{25}Br$	HMPA (5.5)	1-$C_{12}H_{25}OH$	94
6		NMP (15)		75
7	1-$C_8H_{17}Br$	HMPA (5.5)	1-$C_8H_{17}OH$	92
8		NMP (15)		87
9	1-$C_8H_{17}Cl$	HMPA (40)	1-$C_8H_{17}OH$	47[c]
10		NMP (111)		26[c]
11	furan-2-$(CH_2)_4Br$	HMPA (6)	furan-2-$(CH_2)_4OH$	95[d]
12	$C_6H_5COCH_2Br$	NMP (6)	$C_6H_5COCH_2OH$	69
13	(*E*)-$CH_3(CH_2)_6CH{=}CHCH_2Cl$	NMP (5)	(*E*)-$CH_3(CH_2)_6CH{=}CHCH_2OH$ (98); $CH_3(CH_2)_6CHOHCH{=}CH_2$ (2)	96
14	2-$C_8H_{17}I$	HMPA (8)	2-$C_8H_{17}OH$	75
15		NMP (17)		72
16	2-$C_8H_{17}Br$	NMP (24)	2-$C_8H_{17}OH$	64
17	2-$C_{10}H_{21}Br$	NMP (24)	2-$C_{10}H_{21}OH$	78
18	2-bromocyclododecanone	NMP (50)	cyclododecanone-2-OH	70
19	*exo*-2-bromocamphor	NMP (50)	2-hydroxycamphor	0[e]
20	$C_6H_5COCHBrC_6H_5$	NMP (70)	$C_6H_5COCHOHC_6H_5$	70
21	2-$C_8H_{17}OTs$	HMPA (8)	2-$C_8H_{17}OH$	72
22		NMP (15)		75
23	(−)-2-$C_8H_{17}OTs$	HMPA[f] (8)	(−)-2-$C_8H_{17}OH$ (30);[g] and (+)-2-$C_8H_{17}OH$ (70)[g]	71
24	(−)-2-$C_8H_{17}OTs$	NMP[f] (15)	(−)-2-$C_8H_{17}OH$ (19);[g] (+)-2-$C_8H_{17}OH$ (81)[g]	70
25	cyclododecyl-OTs	NMP (15)	cyclododecene (98);[h] cyclododecanol (2)[h]	71
26	menthol tosylate	NMP (15)	*p*-menthenes	58
27	1-dodecene epoxide	NMP[f] (48)[j]	1,2-dodecadiol	96
28	2-methyl-1-undecene epoxide	NMP[f] (48)[j]	2-methyl-1,2-undecadiol	93
29	1-$C_{12}H_{25}I$	NMP/CH_3OH[i] (20)[j]	1-$C_{12}H_{25}OCH_3$	70
30	1-$C_{12}H_{25}Br$	NMP/CH_3OH[i] (36)[j]		68
31	2-$C_8H_{17}Br$	NMP/CH_3OH[i] (48)[j]	2-$C_8H_{17}OCH_3$	70

[a] Contains 15% (v/v) H_2O unless otherwise specified; conducted at 100 °C. [b] Yields represent isolated, purified products unless otherwise specified. [c] The remaining was starting material as determined by GC. [d] Result by Professor A. B. Smith, III, and Mr. E. Koft (University of Pennsylvania). [e] No reaction, starting material returned. [f] $NaHCO_3$ added to neutralize any acid formed. [g] Determined by optical rotation (neat). [h] Cis/trans ratio of 81:19 and relative yields determined by GC. [i] 15% (v/v) CH_3OH. [j] 130 °C reaction temperature.

peroxide,[3] and mercuric perchlorate.[4] One recent approach involves increasing the nucleophilicity of poor displacing anions either by phase-transfer techniques[5] or by employment of S_N2 rate-enhancing polar aprotic solvents.[6] Indeed, chromate anion, normally an impotent nucleophile, effectively displaces alkyl halides when solubilized in $CHCl_3$ with tetraalkylammonium salts[7] or in hexamethylphosphoramide (HMPA) in the presence of crown ethers.[8] The resulting chromate esters are subsequently cleaved to afford carbonyls.

In an attempt to discover a mild process for alcohol production from halides, we probed the possibility of using bicarbonate anion as a nucleophile utilizing combinations of phase-transfer reagents, polar aprotic solvents, and water to dissolve and enhance the nucleophilicity of $NaHCO_3$. However, although this was not successful, we observed that the combination of water and the polar aprotic solvents HMPA or *N*-methyl-2-pyrrolidone (NMP) alone provide potent, selective, and neutral (in the presence of $NaHCO_3$) sources of nucleophilic oxygen for the conversion of alkyl halides and sulfonate esters to alcohols and the opening of terminal epoxides to 1,2-diols. Furthermore, alcohols also display increased nucleophilicity and afford ethers. This note offers these systems as convenient synthetic alternatives to available processes.

Experimentation demonstrated that 15% (v/v) solutions of water in either HMPA or NMP at 100–130 °C effectively converts primary and secondary iodides, bromides, and tosylates to alcohols and opens terminal (but not internal[9]) epoxides to 1,2-diols. Table I presents results for a variety of examples and illustrates several features of the reactions. First, good to excellent isolated yields of alcohols are achieved with most substrates. The only exceptions noted were a hindered secondary bromide (entry 19) and cyclic secondary tosylates entries 25 and 26), with the latter two affording alkenes. In all other cases, <2% alkene side products were detected by GLC and/or NMR. Also, dibenzoylbromomethane gave only the debrominated product dibenzoylmethane (NMP, 100 °C; 55 h; 79% yield). The chiral examples (entries 23 and 24) indicated that

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(2) (a) Reich, H. J.; Peake, S. L. *J. Am. Chem. Soc.* **1978**, *100*, 4888. (b) Macdonald, T. L.; Narasimhan, N.; Burka, L. T. *Ibid.* **1980**, *102*, 7760. (c) Davidson, R. I.; Kropp, P. J. *J. Org. Chem.* **1982**, *47*, 1904.

(3) Corey, E. J.; Nicolaou, K. C.; Shibasaki, M.; Machida, Y.; Shiner, C. S. *Tetrahedron Lett.* **1975**, 3183. (b) San Filippo, J., Jr.; Chern, C. I.; Valentine, J. S. *J. Org. Chem.* **1975**, *40*, 1679. (c) Johnson, R. A.; Nidy, E. G. *Ibid.* **1975**, *40*, 1680.

(4) Mckillop, A.; Ford, M. E. *Tetrahedron* **1974**, *30*, 2467.

(5) For reviews, see: (a) Weber, W. P.; Gokel, G. W. "Phase Transfer Catalysis in Organic Synthesis"; Springer-Verlag: New York, 1977. (b) Keller, W. E. "Compendium of Phase-Transfer Reactions and Related Synthetic Methods"; available from Fluka AG, CH-9470 Buchs, Switzerland, 1979.

(6) For reviews, see: Parker, A. J. *Chem. Rev.* **1969**, *69*, 1. Normant, H. *Angew. Chem., Int. Ed. Engl.* **1968**, *6*, 1046; *Russ. Chem. Rev.* (*Engl. Transl.*) **1970**, *39*, 457.

(7) Landini, D.; Rolla, F. *Chem. Ind.* (*London*) **1979**, 213.

(8) Cardillo, G.; Orena, M.; Sandri, S. *J. Chem. Soc., Chem. Commun.* **1976**, 190.

(9) Internal epoxides were recovered even after 48 h at 130 °C.

while substitution occurs principally by inversion (70–81%), significant racemization results under the reaction conditions even in the presence of added $NaHCO_3$ to neutralize any generated acid.[10] Saturated alkyl chlorides react only with reluctance (entries 9 and 10), but displacement of allylic chlorides occurs readily with only meager rearrangement (2%, entry 13). Terminal epoxides (entries 27 and 28) are cleaved, thus providing a mild process for the formation of 1,2-diols. In these cases superior results were obtained with $NaHCO_3$ present.[10,11] Finally, alcohols in place of water also effect substitution to the corresponding ethers (entries 29–31).

Experimental Section

General Reaction Procedure. The process was straightforward for all examples. A solution of the compound (5 mmol) in 15% (v/v) aqueous HMPA or NMP (25 mL) was heated at 100–130 °C (Table I) and the reaction progress monitored by GC or TLC. After completion, the mixture was cooled, diluted with water (50 mL), and extracted with two portions of ether or pentane. The organic phase was washed with three portions of water, dried ($MgSO_4$), and concentrated on a rotary evaporator. Recrystallization or bulb-to-bulb distillation afforded the products, which were analyzed by GC and/or NMR comparisons with authentic samples.

Registry No. 1-$C_{12}H_{25}I$, 4292-19-7; $C_6H_5COCH_2Br$, 70-11-1; (*E*)-$CH_3(CH_2)_6CH{=}CHCH_2Cl$, 70-11-1; 2-$C_8H_{17}I$, 557-36-8; 1-$C_8H_{17}I$, 629-27-6; 1-$C_{12}H_{25}Br$, 143-15-7; 1-$C_8H_{17}Br$, 111-83-1; 1-$C_8H_{17}Cl$, 111-85-3; 2-$C_8H_{17}Br$, 557-35-7; 2-$C_{10}H_{21}Br$, 39563-53-6; $C_6H_5COCHBrC_6H_5$, 1484-50-0; 2-$C_8H_{17}OTS$, 1028-12-2; (−)-2-$C_8H_{17}OTs$, 27770-99-6; 1-$C_{12}H_{25}OH$, 112-53-8; 1-$C_8H_{17}OH$, 111-87-5; $C_6H_5COCH_2OH$, 582-24-1; (*E*)-$CH_3(CH_2)_6CH{=}CHCH_2OH$, 18409-18-2; $CH_3(CH_2)_6CHOHCH{=}CH_2$, 51100-54-0; 2-$C_8H_{17}OH$, 123-96-6; 2-$C_{10}H_{21}OH$, 1120-06-5; $C_6H_5COCHOHC_6H_5$, 119-53-9; (−)-2-$C_8H_{17}OH$, 5978-70-1; (+)-2-$C_8H_{17}OH$, 6169-06-8; 1-$C_{12}H_{25}OCH_3$, 3482-63-1; 2-$C_8H_{17}OCH_3$, 1541-09-9; H_2O, 7732-18-5; $PhCOCH_2Br$, 70-11-1; $NaHCO_3$, 144-55-8; HCO_3^-, 71-52-3; CH_3OH, 67-56-1; HMPA, 680-31-9; NMP, 872-50-4; 2-(4-bromobutyl)furan, 66356-49-8; 2-bromocyclodecanone, 31236-94-9; *exo*-2-bromocamphor, 30462-54-5; menthol tosylate, 7212-65-9; 1-dodecene epoxide, 2855-19-8; 2-methyl-1-undecene epoxide, 54125-40-5; 4-furylbutanol, 19958-66-8; 2-hydroxycyclododecanone, 19025-38-8; cyclododecanol, 1724-39-6; 1,2-dodecadiol, 1119-87-5; 2-methyl-1,2-undecadiol, 84988-54-5; (*Z*)-cyclododecene, 1129-89-1; (*E*)-cyclododecene, 1486-75-5; cyclododecyl tosylate, 27092-44-0.

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(10) For acid-sensitive substrates, 1 or 2 equiv of $NaHCO_3$ may be added to neutralize acid generated. Except for epoxides, this had no effect on yields.

(11) Aqueous bicarbonate has been reported to displace benzylic and allylic halides: Pinck, L. A.; Hilbert, G. E. *J. Am. Chem. Soc.* **1946**, *68*, 751. Burgstahler, A. W.; Nordm, J. C. *Ibid.* **1961**, *83*, 198.

Alkylation of Enolates from β-Dicarbonyl Compounds with Sulfonium Salt Electrophiles

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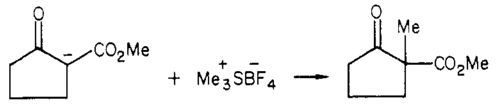
Received July 13, 1982

The alkylation of anions generated from β-dicarbonyl compounds has been extensively investigated.[1] Judicious choice of the electrophile and cation has often permitted selective reaction at oxygen or carbon. Sulfonium salts have not been included in this group of electrophiles[2-4] despite the obvious biological analogue, *S*-adensylmethionine.[5] We recently used the reaction of *S*-ethylthiolanium fluoborate with three enolates from β-keto esters to form 1,5-keto mercaptans.[6] In this note, we report on the potentially useful application of sulfonium salts as electrophiles for the alkylation of β-dicarbonyls that undergo O-alkylation.



1 2 3

Application of a sulfonium salt electrophile offers some unique advantages. Since the leaving group portion, a thioether, is as soft and polarizable as iodide, these electrophiles should promote selective reaction at the soft center of an ambident nucleophile. With asymmetric sulfonium salts, the potential competitive alkyl transfers may be controlled by the choice of sulfur appendages. For instance, cyclic sulfonium salts might undergo alkyl transfer to regenerate a cyclic thioether or might suffer ring opening to provide an ω-keto thioether. Finally, a sulfonium salt cation–electrophile and an enolate anion in a nonpolar solvent represent a new "phase-transfer" type arrangement without any water present.[7,8] This combination has now been examined for the effect on C- vs. O-alkylation.

These sulfonium salts do possess three apparent limitations. First, the electrophilic sulfur appendages should be chosen to facilitate the S_N2 reaction. Secondly, the counterion of the sulfonium salt must be nonnucleophilic to minimize decomposition of the salt. Finally, the ambident nucleophile is limited to species that are not basic enough to generate an ylide from the sulfonium salt.

A recent report indicates that methyl 2-oxocyclopentanecarboxylate undergoes both carbon and oxygen alkylation with a variety of electrophiles.[9] The sodium enolate from this compound affords only carbon alkylation with trimethylsulfonium fluoborate (**2**), *S*-ethylthioxanium fluoborate (**4**), *S*-ethylthiolanium fluoborate (**6**), and *S*-ethyl 5,6-dihydro-4-methyl-2*H*-thiapyranium fluoborate (**8**; Table I). Although the percentage of carbon alkylation is somewhat higher than that in other reports,[9,10] this observation is probably not significant.

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(2) For the only examples of C-alkylation, see: (a) Reference 55 cited ref 1b; Lange, B. C. unpublished results. (b) Badet, B.; Julia, M.; Ramirez-Munoz, M. *Syntheses* **1980**, 926–929; Table 3, entry 6.

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(8) Noyori, R.; Nishida, I.; Sakata, J. *J. Am. Chem. Soc.* **1981**, *103*, 2106–2108.

(9) Singh, J. *J. Org. Chem.* **1980**, *45*, 3368–3369.

(10) See footnote 10 in ref 9. Mayer, R. "Newer Methods of Preparative Organic Chemistry"; Foerst, W., Ed.; Academic Press: New York, 1961; Vol. 2, pp 101–132. Ide, J.; Sakai, K. *Tetrahedron Lett.* **1976**, 1367–1370.

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