Table I. Carbethoxylation of Octanonitrile

Base	Molar equiv base	Carbethoxylating agent	Rxn temp, °C	% yield	% GC purity
$NaN[Si(CH_3)_3]_2$	2.5	$(C_2H_5O)_2C{=}O$	RT	11	99
$NaN[Si(CH_3)_3]_2$	2.3	$ClCO_2C_2H_5$	RT	21	99
$NaN[Si(CH_3)_3]_2$	2.1	$ClCO_2C_2H_5$	−74	49	87
$LiN(i\text{-}Pr)_2$	2.3	$ClCO_2C_2H_5$	−74	85–87	98
$LiN(i\text{-}Pr)_2$	2.3	$(C_2H_5O)_2C{=}O$	−74	76	99

Table II. Carbethoxylation of Alkylacetonitriles

Registry no.	Nitrile	Molar equiv LDA	Molar equiv diethyl carbonate	Rxn temp, °C	% yield	% VPC purity	Bp, °C (mm)
625-28-5	Isovaleronitrile	2.4	1.02	−78	56	95	122–123 (41)[b]
628-73-9	Capronitrile	2.3	1.05	−78	76	97	119–120 (20)[c]
5732-87-6	Cyclopentylacetonitrile	2.0	1.05	−78	79	95	137–138 (19)[d]
4435-14-7	Cyclohexylacetonitrile	2.3	1.05	−78	86	97	147–148 (13)[e]
638-65-3	Stearonitrile	2.3	1.05	−15[a]	81		167–174 (0.15)[f]

[a] Stearonitrile is insoluble in THF at −78 °C. [b] Lit.[4] 111–113 °C (22 mm). [c] Lit.[4] 128–129 °C (23 mm). [d] Lit. 135–138 °C (17 mm),[9a] 129 °C (12 mm).[9b] [e] Lit. 146–148 °C (12 mm).[10] [f] Mp 36–37.5 °C, lit.[4] bp 167–180 °C (2 mm), lit.[4] mp 14–18 °C.

product, which could only be removed by careful fractional distillation.

The method was extended to other alkylacetonitriles and the yields of pure, distilled carbethoxylated product were excellent (Table II).

The α-carbethoxylation method was not devised to replace more classical approaches to these compounds such as cyanoacetate displacement of alkyl halides or Knoevenagel condensation–reduction sequences, but rather to provide a new alternative when such methods fail or cannot be applied in a synthesis of a more complex molecule.

Experimental Section

Ethyl Hexylcyanoacetate. To a flame-dried, N_2-flushed, three-necked 200-mL round-bottomed flask equipped with magnetic stirrer, N_2 inlet, stopper, and serum cap were added 4.75 g (47 mmol) of diisopropylamine and 40 mL of dry THF (freshly distilled from $LiAlH_4$). The solution was cooled to −74 °C (dry ice-2-propanol bath) and 29 mL of 1.6 N *n*-butyllithium in hexane (46 mmol, Foote Mineral Co., Exton, Pa.) was syringed in. The solution was stirred for 10 min at −74 °C and warmed to room temperature during 20 min. After cooling to −74 °C a solution of 2.50 g (20 mmol) of octanonitrile in 15 mL of THF was syringed in during 10 min, and the mixture was allowed to stir for 0.5 h at −74 °C and 0.5 h while it warmed to room temperature. The anion solution was then cooled to −74 °C and a 10-mL solution of 2.48 g (21 mmol) of diethyl carbonate in THF was syringed in during 10 min and allowed to stir for 2.5 h at −74 °C. The reaction was quenched with 10 mL of saturated NH_4Cl. Ether (75 mL) and water (20 mL) were added, and the layers separated. The organic layer was washed successively with 3 × 30 mL of 10% HCl, 3 × 30 mL of H_2O, and 30 mL of brine, and was dried over $MgSO_4$. Filtration and removal of solvent gave 3.86 g of a fragrant yellow oil, which upon fractional distillation (69–71 °C, 0.04 mm) gave 2.97 g of ethyl hexylcyanoacetate, analyzed to be 99% pure by GLC (10 ft × 0.125 in. column of 20% Apiezon L on 60/80 Chromosorb W, injector temperature 240 °C, column temperature 170 °C, detector temperature 280 °C). Lit. 149–150 °C (19 mm),[8a] 136–138 °C (14 mm).[8b] NMR (CCl_4) τ 5.69 (q, J = 7 Hz, 1.93 H), 6.54 (t, J = 7 Hz, 0.91 H), 8.05 (m, 2.50 H), 8.65 (m, 10.81 H), 9.10 (br t, 2.84 H). There are peaks in the IR spectrum (neat sample) at 2250 and 1750 cm^{-1}.

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Registry No.—Ethyl isopropylcyanoacetate, 3213-49-8; ethyl butylcyanoacetate, 7391-39-1; ethyl cyclopentylcyanoacetate, 61788-30-5; ethyl cyclohexylcyanoacetate, 3213-50-1; ethyl hexadecylcyanoacetate, 61788-31-6; octanonitrile, 124-12-9; diethyl carbonate, 105-58-8; ethyl hexylcyanoacetate, 26526-76-1; ethyl chloroformate, 541-41-3.

References and Notes

(1) The University of New Brunswick, Fredericton, N.B., Canada.

(2) Procedures involving alkali metal in neat diethyl carbonate or with ethereal cosolvent: (a) J. B. Niederl and R. T. Roth, *J. Am. Chem. Soc.*, **60,** 2140 (1938); (b) S. Wideqvist, *Ark. Kemi, Mineral. Geol.*, **24B,** 7 (1947); (c) *ibid.*, **26A,** 13 (1948); (d) J. K. Williams, E. L. Martin, and W. A. Sheppard, *J. Org. Chem.*, **31,** 919 (1966); (e) T. Eicher and K. Eiglmeier, *Chem. Ber.*, **104,** 605 (1971).

(3) Procedures involving sodium ethoxide in diethyl carbonate: (a) E. C. Hornung and A. F. Finelli, "Organic Syntheses", Collect. Vol. IV, Wiley, New York, N.Y., 1963, p 461; (b) E. Testa, F. Fava, and L. Fontanella, *Justus Liebigs Ann. Chem.*, **614,** 167 (1958); (c) J. Diekmann, W. R. Hertler, and R. E. Benson, *J. Org. Chem.*, **28,** 2719 (1963); (d) D. J. Sandman and A. F. Garito, *ibid.*, **39,** 1165 (1974).

(4) V. H. Wallingford, D. M. Jones, and A. H. Homeyer, *J. Am. Chem. Soc.*, **64,** 576 (1942).

(5) C. R. Hauser and R. Levine, *J. Am. Chem. Soc.*, **68,** 760 (1946).

(6) D. S. Watt, *Tetrahedron Lett.*, 707 (1974).

(7) D. N. Brattesani and C. H. Heathcock, *Tetrahedron Lett.*, 2279 (1974).

(8) (a) P. E. Gagnon and B. Nolin, *Can. J. Res., Sect. B*, **27,** 742 (1949); (b) O. Wacker and C. Morel, German Offen. 1 928 438 (1969); *Chem. Abstr.*, **72,** 55463 (1970).

(9) (a) S. Archer, British Patent 632 094 (1949); *Chem. Abstr.*, **44,** 6342 (1950); (b) I. Vogel, *J. Chem. Soc.*, 2010 (1968).

(10) W. Bailey and J. J. Daly, *J. Am. Chem. Soc.*, **81,** 5397 (1959).

Application of Complex Formation to the Conformational Analysis of Thioxanthene Sulfoxides, Thianthrene Disulfoxides, and Phenoxathiin Sulfoxide Using Infrared Spectroscopy[1]

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The S–O stretching frequency of sulfoxides normally occurs at about 1050 cm^{-1}.[2] This rather intense vibration is not particularly influenced by the nature of the alkyl or aryl groups bonded to sulfur.[2] Consequently, this vibration has

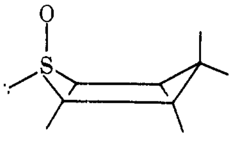
Table I. Infrared Spectra of Thioxanthene 10-Oxides and Related Systems

Registry no.	Compd	R_1	R_2	R_4	$R_{9a'}$	$R_{9e'}$	S(O)	ν_{S-O} (CCl_4), cm^{-1}	ν_{S-O} (CCl_4/ICl), cm^{-1}
61689-16-5	1	H	H	CH_3	H	H	a′	1035	950[a]
61689-17-6	2	Cl	H	CH_3	H	H	a′	1035	956[b]
19019-07-9	3	CH_3	H	Cl	H	H	a′	1040	959[c]
51517-43-2	4	CH_3	H	CH_3	H	H	a′	1035	947[d]
10133-81-0	5	H	H	H	H	H	e′	1041	989, 953
56195-77-8	6	H	H	H	C_2H_5	H	a′	1040	947
55235-94-4	7	H	H	H	$CH(CH_3)_2$	H	a′	1038	949
19018-81-6	8	H	H	H	CH_3	H	e′	1041	990[e]
56195-78-9	9	H	H	H	C_2H_5	H	e′	1042	989
19019-06-8	10	H	H	H	CH_3	CH_3	e′	1044	989
2748-51-8	11	H	H	H			e′,e′	1095	1005[f]
948-44-7	12	H	H	H			e′	1055	1005[g]

[a] 1008 cm^{-1} in $CHCl_3$; 970 cm^{-1} in CCl_4/I_2. [b] 1015 cm^{-1} in $CHCl_3$; 985 cm^{-1} in CCl_4/I_2. [c] 1020 cm^{-1} in $CHCl_3$; 985 cm^{-1} in CCl_4/I_2. [d] 1005 cm^{-1} in $CHCl_3$; 975 cm^{-1} in CCl_4/I_2. [e] 1036 cm^{-1} in $CHCl_3$; 1020 cm^{-1} in CCl_4/I_2. [f] This confirms the original assignment: T. Cairns, G. Eglinton, and D. T. Gibson, *Spectrochim. Acta,* **20,** 159 (1964): 1037 cm^{-1} in CCl_4/I_2. The trans isomer, containing both an a′ and e′ sulfinyl oxygen, produced absorptions at 955 and 991 cm^{-1}, respectively, in CCl_4/ICl. [g] This datum is for CCl_4/I_2. While decomposition in I_2 is sufficiently slow to obtain a spectrum, decomposition occurs too rapidly in ICl. 1035 cm^{-1} in $CHCl_3$.

served as a useful analytical probe to determine the presence of the sulfinyl group but does not appear to have been used nearly as extensively as a conformational probe.[3] As part of our study of the stereochemistry of conformationally restricted diaryl sulfur systems[4] we now have examined the infrared spectra of a number of thioxanthene sulfoxides,[5] and similar systems, of known configuration and conformation and assigned them their S–O stretching frequency. Furthermore, we have examined the effect of complex formation upon the infrared spectra of thioxanthene derivatives of known geometry and demonstrated the value of complexation in determining the conformation of the sulfinyl group.

The sulfoxides examined in this study have either a pseudoaxial (a′) sulfinyl oxygen, I, or a pseudoequatorial (e′) sulfinyl oxygen, II. The geometry of these compounds, deduced by NMR, x-ray, and dipole moment studies, has been described in the literature.[4,5] The sulfinyl stretching vibration for all compounds was assigned using the method of Augdahl and Klaeboe.[6] In this procedure one compares the infrared spectrum in carbon tetrachloride and in carbon tetrachloride containing a halogen or mixed halogen (e.g., iodine or iodine monochloride). Addition of the complexing agent causes the weakening (or even disappearance) of the absorption due to the free sulfinyl group *and* the appearance of a new absorption assigned to the S–O···X_2 complex.[6,7] In several, randomly selected cases these assignments were supported by comparing infrared spectra in carbon tetrachloride and in chloroform, hydrogen bonding being known to shift ν_{S-O} to lower frequencies.[8] The sulfoxides examined include 4-methylthioxanthene 10-oxide (**1**), 1-chloro-4-methylthioxanthene 10-oxide (**2**), 4-chloro-1-methylthioxanthene 10-oxide (**3**), 1,4-dimethylthioxanthene 10-oxide (**4**), thioxanthene 10-oxide (**5**), *cis*-9-ethylthioxanthene 10-oxide (**6**), *cis*-9-isopropylthioxanthene 10-oxide (**7**), *trans*-9-methylthioxanthene 10-oxide (**8**), *trans*-9-ethylthioxanthene 10-oxide (**9**), 9,9-dimethylthioxanthene 10-oxide (**10**), *cis*-thianthrene 9,10-dioxide (**11**), and phenoxathiin 10-oxide (**12**).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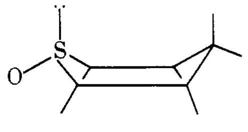
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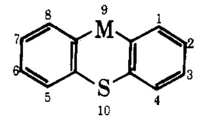

thioxanthene, M = CH_2
thianthrene, M = S
phenoxanthiin, M = O

The results of our study of the effect of the addition of iodine monochloride upon the S–O stretching frequency of thioxanthene sulfoxides are summarized in Table I. It can be seen that ν_{S-O} is quite insensitive to the conformation of the sulfinyl group. Thus, those compounds with an a′ sulfinyl oxygen absorb at approximately 1035 cm^{-1} while those which possess an e′ sulfinyl oxygen absorb at approximately 1042 cm^{-1}. While these are not exactly the same, a frequency difference of approximately 7 cm^{-1} would not, in our opinion, be a difference upon which to base a conformational analysis. Although $\Delta\nu_{S-O}$ is not very sensitive to conformation in these conformationally restricted diaryl sulfoxides, the new absorption of the complexed (with iodine monochloride) sulfinyl group is geometry dependent. Thus, the e′ S–O/ICl complexes exhibit an absorption at about 990 cm^{-1} while the a′ S–O/ICl complexes absorb at about 950 cm^{-1}. Like the uncomplexed absorptions, these bands are not very variable within a given family.

While iodine produced shifts of ν_{S-O} when several thioxanthene sulfoxides were examined, iodine monochloride is the reagent of choice in examining thioxanthene sulfoxides since it gives larger shifts and does not lead to rapid decomposition. Similarly, **11**, which is known to exist in the dipseudoequatorial array, shows a smaller shift of ν_{S-O} in iodine than in iodine monochloride. This suggests that iodine monochloride is the reagent of choice in studying thianthrene oxides. While **12** decomposed rapidly in iodine monochloride/carbon tetrachloride, iodine was a sufficiently mild reagent to permit observation of $\Delta\nu_{S-O}$. Thus the phenoxathiin ring system is better studied using iodine than iodine monochloride. In general, the choice of complexing agent is dictated by the ease of decomposition of the complex, presumably through an intermediate cation.[9]

Most of the thioxanthene derivatives described in Table I are unlikely to alter conformation upon complexation either because of the substituents peri to the sulfinyl group[10] or because of the substitution at C-9.[4] However, that complexation may disturb a conformational distribution when such controlling factors are absent is suggested by the behavior of thioxanthene oxides which lack substituents at C-4 and C-9. For example, three intense absorptions are found in the sulfinyl region[2] of the infrared spectrum of 2-chlorothioxanthene 10-oxide (carbon tetrachloride): 1101, 1081, and 1044 cm^{-1}.[11] In going to chloroform[11] only the absorption at 1044 cm^{-1} disappears while a new, broader absorption appears at 1035 cm^{-1}.[12] This unequivocally[8] assigns the 1044-cm^{-1} absorption (carbon tetrachloride) to ν_{S-O}. The corresponding absorption in **5** occurs at 1041 cm^{-1}. Addition of iodine monochloride to **5** (carbon tetrachloride) causes the absorption at 1041 cm^{-1} to diminish in intensity and produces two new absorptions—at 992 and 953 cm^{-1}. This suggests that the complex formed between **5** and iodine monochloride exists as a mixture of conformers.[13]

Experimental Section

Infrared spectra were obtained on a Perkin-Elmer Model 621 spectrophotometer using solutions 0.02 M in solute and, where indicated, in complexing agent.

All of the compounds have been described by us or are available commercially.[4] No special purification procedures were employed in using iodine monochloride (commercially available).

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References and Notes

(1) Presented at the VII International Symposium on Organic Sulphur Chemistry, Hamburg, 1976.
(2) L. J. Bellamy, "The Infrared Spectra of Complex Molecules", 2nd ed., Wiley, New York, N.Y., 1958, p 358.
(3) For an interesting example see M. Oki, I. Oka, and K. Sakaguchi, *Bull. Chem. Soc. Jpn.*, **42**, 2944 (1969).
(4) A. L. Ternay, Jr., and S. A. Evans, *J. Org. Chem.*, **39**, 2941 (1974).
(5) S. A. Evans and A. L. Ternay, Jr., *J. Org. Chem.*, **40**, 2993 (1975), and references cited therein.
(6) E. Augdahl and P. Klaeboe, *Acta Chem. Scand.*, **18**, 18 (1964); see also P. Klaeboe, *ibid.*, **18**, 27 (1964).
(7) Other, minor changes accompany complex formation (e.g., small changes in bandwidth at half-height). However, no other significant bands disappear from the sulfinyl region.[2]
(8) (a) D. Barnard, J. M. Fabian, and H. P. Koch, *J. Chem. Soc.*, 2442 (1949); (b) W. Otting and F. A. Neugebauer, *Chem. Ber.*, **95**, 540 (1962); (c) T. Gramstad, *Spectrochim. Acta*, **19**, 829 (1963); (d) J. H. S. Green, *ibid.*, **24A**, 1627 (1968).
(9) One would expect that thianthrene or thioxanthene sulfoxides which form particularly stable cations might also be better studied using iodine.
(10) A. L. Ternay, Jr., L. Ens, J. Herrmann, and S. Evans, *J. Org. Chem.*, **34**, 940 (1969).
(11) 0.02 M.
(12) The absorptions at 1101 and 1081 cm^{-1} diminish slightly in intensity, shift to lower frequency ($\Delta\nu = 3$ cm^{-1}), *but* diminish in bandwidth at half-height by approximately 15%. The bandwidth at half-height of the 1035 cm^{-1} absorption is 2.3 times as great as that of the 1044 cm^{-1} band in carbon tetrachloride.
(13) We have demonstrated that thioxanthene sulfoxide assumes a predominantly a′ conformation in trifluoroacetic acid, presumably owing to increased size of the sulfinyl group upon hydrogen bonding to the solvent: A. L. Ternay, Jr., J. Herrmann, and B. R. Hayes, submitted for publication.

Synthesis of Dibenzyl Ethers via the Dehydration of Benzylic Alcohols in Dimethyl Sulfoxide

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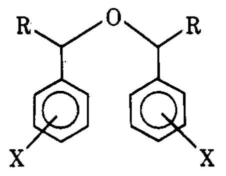
During the course of our investigations of intramolecular excimer formation of dibenzyl ethers,[1] we developed a general method of preparing substituted benzyl ethers of structure I in high yields from the respective alcohols using dimethyl sulfoxide as the dehydrating agent. The ethers could be prepared with either electron-donating or electron-withdrawing substituents X, and with R = H or alkyl. This method was preferable to the Williamson synthesis or simple acid catalyzed dehydration which often gave low yields or mixtures of products.[2]



R = H, alkyl

I

Dimethyl sulfoxide mediated dehydration of 1-alkylcycloalkanols and secondary and tertiary benzylic alcohols to olefins has been well documented by Traynelis and co-workers.[3,4] Me_2SO-catalyzed dehydration of diols to cyclic ethers has also been reported.[4,5] In both cases low ratios of alcohol to Me_2SO (1:3 to 1:12) were employed. When the ratio of alcohol to Me_2SO was raised to 1:1 or 3:1, more ether was produced at the expense of olefin, but the product still consisted of a complex mixture of olefin, ether, ketone, and starting material.[4]

We have observed that modification of earlier conditions[4] to very high ratios of alcohol:Me_2SO (16:1) completely suppresses the formation of olefins and oxidized products and provides high yields of ethers (Table I).

When lower ratios of alcohol to Me_2SO (12:1, 3:1) were tried, significant amounts of olefin and oxidized products were obtained. In general, secondary benzyl alcohols reacted faster than primary benzyl alcohols, and alcohols containing electron-donating groups on the ring reacted faster than those containing electron-withdrawing groups. Dehydration of *p*-methoxybenzyl alcohol proceeded smoothly in Me_2SO to give an 85% yield of ether, though it polymerized, rather than dehydrated, in the presence of sulfuric acid or $ZnCl_2$. An unsymmetrical cyclohexyl (α-methylbenzyl) ether also could be prepared if an excess of cyclohexanol were present in the reaction mixture.

A limitation of this method is indicated by the last entry in the table. No product was obtained upon heating *p*-nitrobenzyl alcohol in Me_2SO even after 22 h. It has been proposed that the radical decomposition of Me_2SO to strong acids is responsible for its apparent catalytic action in a variety of reactions.[6,7] The lack of reactivity of *p*-nitrobenzyl alcohol is therefore probably due to the presence of the radical quenching nitro group. In fact, addition of nitrobenzene was sufficient to significantly inhibit the reaction of *p*-methylbenzyl alcohol with Me_2SO presumably by preventing the production of strong acids.

The reaction also appeared to be accelerated by oxygen. Thus, *p*-fluorobenzyl alcohol was unreactive in the presence of dimethyl sulfoxide at 175 °C under a nitrogen atmosphere, though it reacted completely after 8 h in air. This is consistent with other reports that oxygen is a requisite ingredient for the formation of strong acids from Me_2SO at elevated temperatures.[7,8]

The detailed mechanistic pathway of Me_2SO-catalyzed dehydrations has been the subject of some speculation. Traynelis has shown that a carbenium ion is implicated in the dehydration of alcohols to olefins in Me_2SO.[3,4] On the other hand, Gillis and Beck suggested an S_N2-type mechanism for the formation of tetrahydrofurans from 1,4-diols, where dimethyl sulfoxide aids in the removal of a proton from the attacking group while simultaneously stabilizing the leaving group (1).[5]