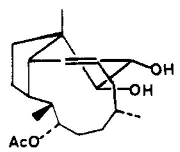
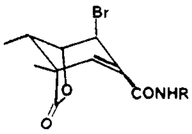
(HC/HC) system **101**, the half-chair ⇌ boat (HC/B) system **102**, and the chair,chair ⇌ chair,twist (CC/CT) fusion composite system **103**. For each of these systems



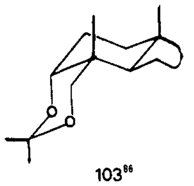
101[92]

$\Delta E_D = 1.4$ (HC/HC)



102[93]

$\Delta E_D = 2.0$ (HC/B)

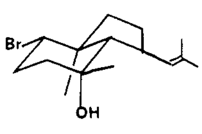


103[86]

$\Delta E_D = 4.6$ (CC/CT)

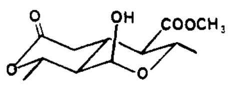
is shown the conformation predicted and the computed total destabilization energy (ΔE_D, kcal/mol) found to favor this conformation over its well-defined alternative. In each case the significant energy difference computed leads to prediction of the geometry actually established by the X-ray data.

Finally, several naturally occurring systems (**104**–**107**) are shown, each of which contains one or a pair of six-membered rings with a flexibility classification of distortable. For each of these is shown the total destabilization energy (E_D, kcal/mol) computed for the single well-defined chair conformation available. In each case this number is below the appropriate energy cutoff value and leads to acceptance of the chair geometry shown.



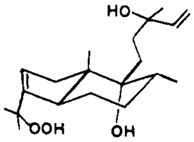
104[94]

$E_D = 5.0$



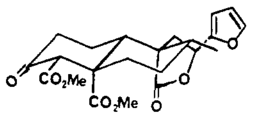
105[95]

$E_D^A = 0.8$ $E_D^B = 1.9$



106[96]

$E_D = 4.2$



107[97]

$E_D^A = 1.4$ $E_D^B = 3.9$

Again, these assignments are supported by the X-ray data.

Acknowledgment. This research was assisted by a grant from the National Institutes of Health and by a fellowship from the National Research Council of Canada. We thank Professor A. Peter Johnson, Polytechnic of North London, and Professor Robert D. Stolow, Tufts University, for their important contributions during the development of these ideas.

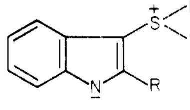
Indole-3-sulfonium Ylides and Related Sulfonium Salts. Chemical and Physical Properties

Kyong-Hwi Park and G. Doyle Daves, Jr.*

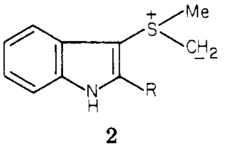
Department of Chemistry and Biochemical Sciences, Oregon Graduate Center, Beaverton, Oregon 97005

Received November 26, 1979

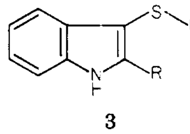
Acid–base titration of the sulfonium salt–sulfonium ylide pair dimethyl(1*H*-indol-3-yl)sulfonium 3-(dimethylsulfonio)indolide, the corresponding 2-methyl or 2-phenyl analogues, or the homologous 3-diethylsulfonium compounds resulted, in each case, in a hysteresis; i.e., titration of the sulfonium ylide with acid gave a different set of pH values from those observed upon titration of the sulfonium salt with base. In related studies comparison of ultraviolet spectra of the sulfonium salts and ylides in anhydrous dioxane and in water revealed significant differences. ^{1}H NMR spectra of sulfonium salts in aqueous or aqueous trifluoroacetic acid solutions revealed the formation of a new species which (a) exhibited an acid–base titration hysteresis indistinguishable from that of the precursor salt, (b) exhibited ions in the mass spectra corresponding to a sulfonium salt plus a molecule of water, and (c) reverted to the precursor salt upon attempted purification. These results are consistent with covalent hydration across the highly polarized C-2, C-3 double bond of the indole ring.



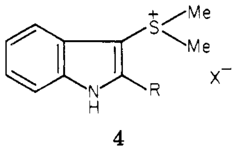
1



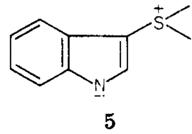
2



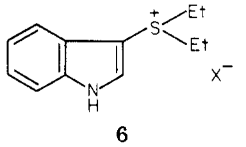
3



4



5



6

a, R = H; b, R = Me; c, R = Ph

We have reported that 3-(dimethylsulfonio)indolide (**1a**), a stable, crystalline sulfonium ylide, (a) is unusually basic (the pK_a of the conjugate acid, sulfonium salt **4a**, is >11) and (b) incorporates deuterium into the *S*-methyl groups when dissolved in deuteriochloroform or deuteriomethanol (requiring the intermediacy of methylidene ylide **2**).[1] More recently, we have made a detailed study of ^{13}C and ^{1}H NMR spectra of **1a**, its 2-methyl (**1b**) and 2-phenyl (**1c**) analogues, precursor 3-(methylthio)-1*H*-indoles (**3**), and dimethyl(1*H*-indol-3-yl)sulfonium salts (**4**) in aprotic solvents.[2] In the present report, we describe the preparation of these compounds and of the related 3-(diethylsulfonio)indolide (**5**) and corresponding sulfonium salt **6** and studies of various aspects of their chemical and physical properties including acid–base titration phenomena, ultraviolet spectroscopy in protic and aprotic solutions, ^{1}H NMR spectra in protic solvents, and electron ionization and field desorption mass spectrometry.

---

(1) G. D. Daves, Jr., W. R. Anderson, Jr., and M. V. Pickering, *J. Chem. Soc., Chem. Commun.*, 301 (1974).

(2) K. H. Park, G. A. Gray, and G. D. Daves, Jr., *J. Am. Chem. Soc.*, 100, 7475 (1978).

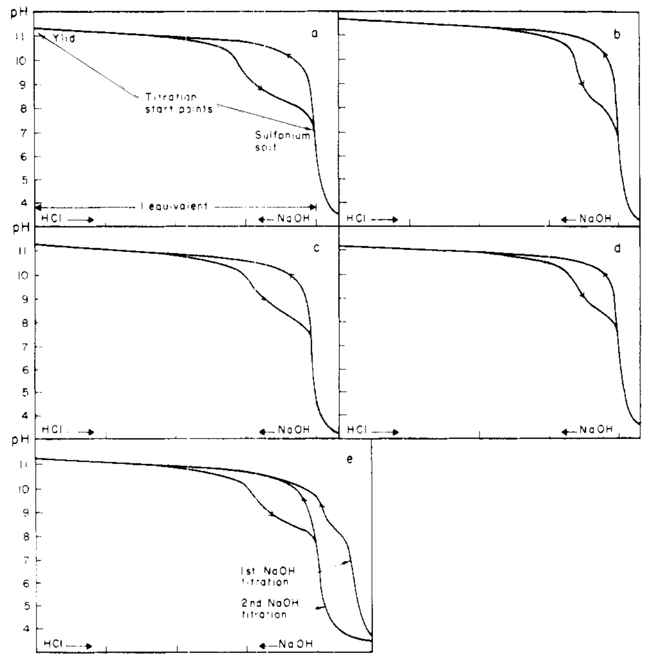


Figure 1. Acid-base titration profiles of sulfonium ylide (1, 5)–sulfonium salt (4, 6) systems. (a) Sulfonium ylide 1a–sulfonium salt 4a (X = I); (b) 1b–4b (X = I); (c) 1c–4c (X = Cl); (d) 5–6 (X = I); (e) product(s) formed by warming an aqueous trifluoroacetic acid solution of sulfonium salt 4b (initial titration of the acidic solution was with sodium hydroxide).

Results

Syntheses. 3-(Methylthio)indoles **3a**[3,4] and **3b**[4] were synthesized by the method of Harris.[5] Thioethers **3a** and **3b** were then methylated (methyl iodide) and the corresponding sulfonium salts (**4a,b**, X = I) were converted to stable sulfonium ylides by treatment with sodium hydride in ether (**4a** → **1a**) or by use of an anion-exchange resin (**4b** → **1b**). Analogous methods were used to prepare the *S*-diethyl analogues **5** and **6**. Preparation of compounds in the 2-phenyl series was accomplished by acid-catalyzed reaction of 2-phenylindole with dimethyl sulfoxide to yield sulfonium salt **4c**[6] (X = Cl) directly, followed by anion exchange to yield ylide **1c**,[6] or by thermal demethylation to yield 3-(methylthio)-2-phenylindole (**3c**).

Acid–Base Titration Phenomena. To determine dissociation constants for the system sulfonium salt (**4**) $\rightleftarrows$ ylide (**1**) and to determine its stability, we titrated methanolic solutions of ylides **1a–c** and **5** with hydrochloric acid and then back-titrated with sodium hydroxide or, alternatively, we titrated solutions of the sulfonium salts **4** and **6** with sodium hydroxide and then with hydrochloric acid, as described by Speziale and Ratts.[7] Surprisingly, in each instance (Figure 1), hysteresis was observed; i.e., titration of the sulfonium ylides **1** and **5** with acid gave a different set of pH values from those observed upon titration of sulfonium salts **4** and **6** with base. The stability of the system was demonstrated when retitration (e.g., with acid, then base, then acid again) in either direction substantially reproduced the original curve. Titration of the products formed by warming aqueous trifluoroacetic acid solutions of sulfonium salts **4b** or **6** (see ^{1}H NMR Spectra in Protic Solvents) proceeded similarly. Within the pH range of a hysteresis loop the pH of the solutions drifted slowly toward values intermediate between the acid and base titration curves.

Using the data for the sodium hydroxide titrations, we calculated[8,9] pK_a values for sulfonium salts **4a–c** and **6** of 11.09, 11.28, 10.88, and 11.02, respectively. It is noteworthy that these values are much higher than pK_a values reported for carbonyl stabilized sulfonium ylides which are in the range 6.5–8.1.[10,13]

Table I. Ultraviolet Spectra of 3-(Dimethylsulfonio)indolides (1), 3-(Methylthio)-1*H*-indoles (3), and Dimethyl(1*H*-indol-3-yl)sulfonium Salts (4) in Water and Dioxane

compd	λ_{max}, nm (ϵ) H$_2$O	dioxane
1a	261 (6100)	262 (7200)
1b	*a*	273 (6900)
1c	291 (14 000), 237 (25 000)	301 (11 000), 237 (17 000)
3a	277 (4400)	273 (5500)
3b	285 (6200), 280 (6700)	272 (9000)
3c	299 (16 000), 235 (22 000)	301 (13 000), 237 (14 000)
4a, X = I	260 (5500)	279 (5600)
4b, X = I	*a*	276 (8500)
4c, X = I	288 (10 000), 235 (14 000)	301 (11 000)

[a] Broad absorption beginning ~300 nm with increasing intensity toward shorter wavelength; no discernible maxima.

Ultraviolet Spectra. The UV spectra of sulfonium ylides **1a–c**, sulfonium salts **4a–c** and the corresponding 3-(methylthio)indoles **3a–c** in water and in an aprotic solvent (dioxane) were obtained to characterize differences in the respective chromophores and to investigate possible interactions of protic solvents with the sulfonium salts and/or ylides. Data from this study are contained in Table I.

The UV spectra for 3-(methylthio)-1*H*-indole (**3a**) in both protic and aprotic solutions, although exhibiting less fine structure owing to sulfur conjugation with the indole nucleus, exhibit maxima little displaced from those of indole,[14,15] suggesting relatively little involvement of sulfur electrons in the chromophore. In dioxane solution, the UV behavior of the three compound classes, thioethers (**3**), sulfonium salts (**4**), and sulfonium ylides (**1**), are similar. In water, however, the situation is quite different. Most strikingly, in aqueous solution dimethyl(2-methylindol-3-yl)sulfonium iodide (**4b**, X = I) and 2-methyl-3-(dimethylsulfonio)indolide (**1b**) exhibit no distinct UV maxima, indicating that in water the indole chromophore of these compounds is not intact.

^{1}H NMR Spectra in Protic Solvents. The ^{1}H NMR spectra of ylides **1a–c** and **5** in water or methanol (Table II) do not display any important differences from those

---

(3) T. D. Lee, M. V. Pickering, and G. D. Daves, Jr., *J. Org. Chem.*, **39**, 1106 (1974).

(4) P. G. Gassman, T. J. van Bergen, D. P. Gilbert, and B. W. Cue, Jr., *J. Am. Chem. Soc.*, **96**, 5495 (1974).

(5) R. L. N. Harris, *Tetrahedron Lett.*, 4465 (1969).

(6) J. Hocker, K. Ley, and R. Merten, *Synthesis*, 334 (1975).

(7) A. J. Speziale and K. W. Ratts, *J. Am. Chem. Soc.*, **85**, 2790 (1963).

(8) A. Albert and E. P. Serjeant, "The Determination of Ionization Constants", Chapman and Hall: London, 1971; Chapter 1.

(9) A. Albert, *Angew. Chem., Int. Ed. Engl.*, **6**, 919 (1967).

(10) K. W. Ratts and Y. N. Yao, *J. Org. Chem.*, **31**, 1185 (1966).

(11) K. W. Ratts, *J. Org. Chem.*, **37**, 848 (1972).

(12) A. W. Johnson and R. T. Amel, *J. Org. Chem.*, **34**, 1240 (1969).

(13) A. W. Johnson and R. B. LaCount, *Tetrahedron*, **9**, 130 (1960).

(14) W. A. Remers in "Indoles", W. J. Houlihan, Ed., Wiley-Interscience: New York, 1972; Part 1, p. 21.

(15) A. I. Scott, "Interpretation of the Ultraviolet Spectra of Natural Products", Pergamon Press: New York, 1964; p. 174.

Table II. ^{1}H NMR Chemical Shifts^a for Indolesulfonium Salts 4 and 6 and Indolesulfonium Ylides 1 and 5 in Protic Solvents

compd	solvent/condition	δ, $-SMe_2^+$	δ, $-SEt_2^+$	δ, C-2 Me
1a	D_2O	3.34		
4a, X = I	D_2O	3.41		
	D_2O/F_3CCOOH (9:1)	3.13		
1b	CD_3OD	3.12		2.50
4b, X = I	CD_3OD	3.36		2.66
	D_2O/2 days, 25 °C	2.92,^{b} 3.24		2.41,^{b} 2.62
	D_2O/F_3CCOOH (9:1)	3.26		2.62
	$D_2O/F_3CCOOH/\Delta$	2.90,^{b} 3.28		2.39,^{b} 2.64
	separated oily fraction/CD_3OD	3.09		2.42
4c, X = Cl	D_2O/F_3CCOOH	2.70,^{b} 3.18		
6, X = I	D_2O		1.35 (Me) 3.83^c (CH_2)	
	D_2O/F_3CCOOH (9:1)		0.94,^{b} 1.33 (Me) 4.41,^{b} 3.76 (CH_2)	
	D_2O/F_3CCOOH (7:3)		1.18 (Me) 3.60^c (CH_2)	

[a] Ppm from external Me_4Si (D_2O, D_2O/TFA); ppm from internal Me_4Si (CD_3OD). [b] Intensity of resonance increases upon heating of sample. [c] Overlapping quartets centered at this chemical shift.

in aprotic solvents.[2] However, the spectra of the corresponding sulfonium salts (**4a–c**, **6**) are quite revealing (Table II, Figure 2). When a solution of 2-methylindolesulfonium salt **4b** (X = I) in D_2O was allowed to stand at room temperature for 24–48 h, a new set of methyl resonances appeared (Figure 2a). The reaction leading to the observation of these new resonances was facilitated by the addition of trifluoroacetic acid and/or by warming the solution (Figure 2b). After the solution cooled, an oil separated.[16] A ^{1}H NMR spectrum of this material in deuteriomethanol (Figure 2c) exhibits methyl resonances, δ 2.42 (C_2–Me) and 3.09 ($-SMe_2^+$) and aromatic proton resonances different from those of either sulfonium salt **4b** (X = I) (Figure 2d) or ylide **1b** (Table II).

When diethylsulfonium salt **6** (X = I) or 2-phenylindolesulfonium salt **4c** (X = Cl) was dissolved in aqueous trifluoroacetic acid, resonances indicative of the formation of new species were also observed (Table II, Figure 2e). Attempts to demonstrate this phenomenon with dimethyl(indol-3-yl)sulfonium iodide **4a** (X = I) were unsuccessful (Table II).

Mass Spectra. Electron ionization (EI) mass spectra (Table III) of indolesulfonium ylides **1a–c** exhibit molecular ions ($M^+\cdot$) and ions corresponding to $(M - Me)^+$. Under similar conditions, the corresponding sulfonium salts (**4a–c**) do not yield molecular ions or ions corresponding to the sulfonium cations. Instead, ions are observed at *m/e* 163, 178, and 239, respectively, which correspond to loss of CH_3X from the sulfonium salts. Using field desorption (FD) mass spectrometry, spectra of the sulfonium salts (Table III) were obtained which exhibit sulfonium cations (MH^+) and ions corresponding to the processes $MH^+X^- - HX$ (i.e., the molecular ion of the corresponding sulfonium ylide) and $MH^+ - Me$. At higher emitter temperatures, ions corresponding to the process $MH^+X^- - HX + Me$, i.e., ylide formation and intermolecular methyl group transfer,[17] are observed. Ylide **1b** exhibited FD mass spectrometric behavior indistinguishable from that of the corresponding sulfonium salt (**4b**).

Ylide **1b** and sulfonium salt **4b** were examined by a new EI mass spectrometric technique termed electron ionization–flash desorption[18] which has yielded spectra of thermally unstable and/or essentially involatile compounds including the quaternary ammonium compound, acetyl-

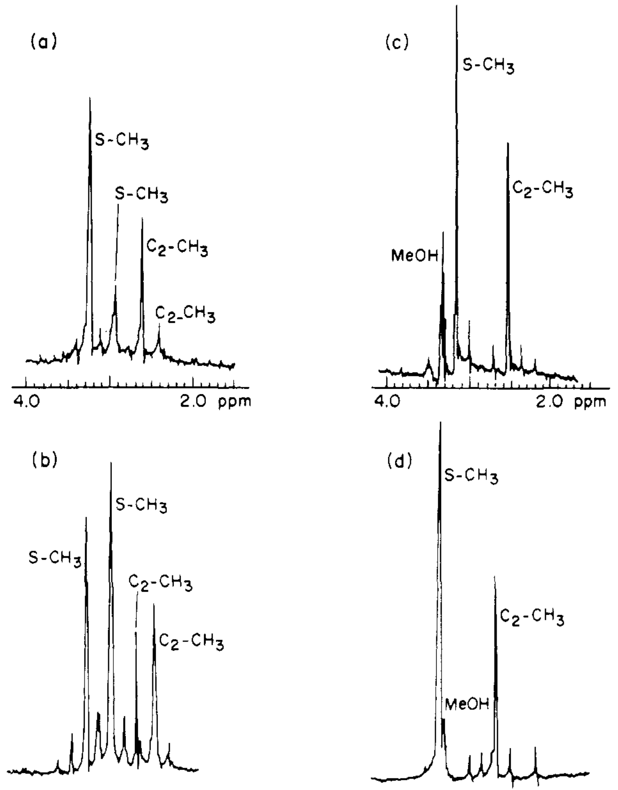


Figure 2. The S-Me(Et) and C-2 methyl regions of the ^{1}H NMR spectra of sulfonium salts **4b** (X = I) and **6** (X = I) in protic solvents. Because external tetramethylsilane (sealed capilliary) was used, spinning side bands are apparent. (a) Sulfonium salt **4b** (X = I) in D_2O after 2 days at 25 °C; (b) sulfonium salt **4b** (X = I) in D_2O/F_3CCOOH (9:1) heated in a water bath for 1 h; (c) separated oily fraction from sample used to obtain spectrum b in CD_3OD; (d) sulfonium salt **4b** (X = I) in CD_3OD; (e) sulfonium salt **6** (X = I) in D_2O/F_3CCOOH (9:1).

---

(16) Attempts to purify these materials resulted, in each case, in reisolation of the original sulfonium salt.

(17) See, for example: G. W. Wood and P. Y. Lau, *Org. Mass. Spectrom.*, 10, 1147 (1975).

(18) G. D. Daves, Jr., *Acc. Chem. Res.*, 12, 359 (1979).

Table III. Selected Ions Observed in Mass Spectra of Sulfonium Ylides 1 and Salts 4

compd	ionization mode[b]	ion (m/e)[a]: $[M(MH) - Me]^+$	$M^{+\cdot}$	MH^+	$[M + Me]^{+\cdot}$	$[M + H_2O]^{+\cdot}$	$[M + Me + OH^-]^{+\cdot}$
1a	EI	162	177				
4a, X = I	EI	163					
1b	EI	176	191				
	FD	177	191	192	206[c]		
	EI*	177	191	192	206[c]		223
4b, X = I	EI	177					
	FD	177	191	192	206	209	
	EI*	177	191	192	206		223
1c	EI	238	253				
4c, X = I	EI	239					

[a] $M^{+\cdot}$ is used to designate the molecular ion of ylides; MH^+ denotes corresponding sulfonium ions. [b] EI, conventional electron ionization; FD, field desorption; EI*, electron ionization flash desorption.[18,19] [c] Observed only when emitter heating current exceeds 10 mA.

Table IV. Selected Ions Observed in Mass Spectra of Products Formed by Treatment of Sulfonium Salts (4a–c, 6) with Aqueous Trifluoroacetic Acid

product of sulfonium salt	ionization mode[b]	ion observed, at m/e[a]: $[M(MH) - Me]^+$	$M^{+\cdot}$	MH^+	$[M + Me]^+$	$[M + H_2O]^{+\cdot}$	$[M + Me + OH^-]^{+\cdot}$
4a, X = I	EI*	162	177	178	192	195	209
4b, X = I	EI*	177	191	192		209	223
	FD	177	191	192	206		
4c, X = Cl	EI*	239	253	254	268	271	
6, X = I	EI*	191	205	206		223	237

[a] $M^{+\cdot}$ is used to designate the molecular ion of ylides; MH^+ denotes corresponding sulfonium ions. [b] EI*, electron ionization flash desorption;[18,19] FD, field desorption.

choline,[18] underivatized disaccharides,[18,19] peptide amides,[18,20] and sodium and potassium salts of carboxylic acids.[18,21] The method involves rapidly heating (~0.1 s to >1200 °C) a sample within the ion source of an electron ionization mass spectrometer.[18,19] The spectrum of ylide **1b** obtained by EI–flash desorption exhibited ions at m/e 177, 191, 192, and 206 present in the FD mass spectrum of **1b** and, in addition, exhibited an ion at m/e 223. The ion at m/e 223 corresponds formally to the molecular ion of a species produced by addition of the elements of methanol to **1b**. The spectrum of sulfonium salt **4b** produced by this method was similar, exhibiting not only the ion at m/e 223 but also an ion at m/e 209 corresponding formally to **1b** + H_2O. It is noteworthy that for these experiments **1b** and **4b** were deposited onto mass spectrometer sample probes by evaporation of aqueous solutions. Thus it seems probable that ions at m/e 209 and 223 arise by association of water with the ylide (sulfonium salt) without (m/e 209) and with (m/e 223) subsequent intermolecular methyl transfer.[17] Table III contains a summary of results of the various mass spectrometric experiments.

Finally, the oily products produced by warming sulfonium salts **4a**, **4b**, **4c**, and **6** in aqueous trifluoroacetic acid (see above) were studied by mass spectrometry. In each instance, the EI–flash desorption mass spectrum obtained exhibited ions which arise (formally) by addition of water to (and loss of HX from) the sulfonium salt. In the one compound examined by FD (that obtained from **4b**) no evidence for a hydrated species was observed. These experiments are summarized in Table IV.

Discussion

The observation of a hysteresis upon acid–base titration of the sulfonium ylide (**1**)–sulfonium salt (**4**) system (Figure 1) indicates that a slow and quantitative interconversion of two or more substances occurs.[8] By ^1H NMR spectrometry of sulfonium salts in protic (but not in aprotic[2]) solvents, two discrete species are observable (Figure 2). Isolation of the new species formed from sulfonium salts **4** in protic solvents, attempts to purify it,[16] acid–base titration (Figure 1), or mass spectrometric analysis (Table IV) established that formation of the new species involved no important structural change since it readily reverts to sulfonium salt (**4**).

In an attempt to assign structure to the species formed in aqueous solution, we have considered the three possibilities deemed most likely by Albert;[9] i.e., the interconverting substances are (a) products of ring opening and closing reactions, (b) tautomers, or (c) a compound(s) and corresponding covalent hydrate(s). The indole structure appears to preclude the first noted possibility which involves a ring–chain equilibrium. The possibility that some form of tautomerism accounts for the observed phenomena is also unlikely. Tautomerism involving ylide **1** and methylidene ylide **2**, which accounts for facile exchange of ylide methyl hydrogens,[1,6] cannot account for the titration hysteresis since the hysteresis occurs at pH values where the concentration of sulfonium salt **4** significantly exceeds that of ylide **1**. Moreover, 3-(diethylsulfonio)indolide (**5**), for which a less favorable, secondary carbanion tautomer (corresponding to **2**) is required, exhibits an acid–base titration hysteresis (Figure 1) like those of the methyl analogues (**1** and **4**). Other tautomers, particularly the C-3 protonated sulfonium salt **7**, are possible but unsupported

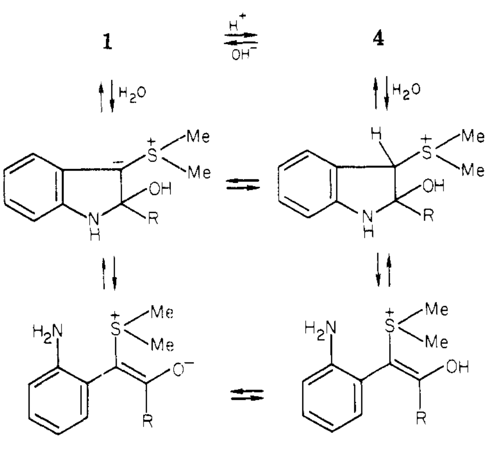
---

(19) W. R. Anderson, Jr., W. Frick, and G. D. Daves, Jr., *J. Am. Chem. Soc.*, **100**, 1974 (1978).

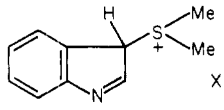
(20) W. R. Anderson, Jr., W. Frick, G. D. Daves, Jr., D. F. Barofsky, I. Yamaguchi, D. Chang, K. Folkers, and S. Rosell, *Biochem. Biophys. Res. Commun.*, 78, 372 (1977).

(21) G. D. Daves, Jr., and W. R. Anderson, Jr., *Int. J. Mass Spectrom. Ion Phys.*, **30**, 385 (1979).

Scheme I



by the appearance of appropriate resonances in ^1H NMR spectra.[22]



7

We suggest that the phenomena observed are owing to covalent hydration. Substrate covalent hydration as a source of anomalous ionization constants, acid–base titration phenomena (Figure 1), and ultraviolet (Table I) and NMR spectra (Figure 2, Table II) was first reported by Albert;[23,24] subsequently more extensive studies have been made.[9,25,26]

The available data—acid–base titration hysteresis (Figure 1), altered UV chromophores in protic solvents (Table I), appearance of a second species in ^1H NMR spectra of sulfonium salts 4 (Figure 2, Table II), and observation of ions possessing an added water molecule in mass spectra (Tables III and IV)—are consistent with addition of a molecule of water across the highly polarized C-2, C-3 double bond of the 3-(dimethylsulfonio)indole system (1–4) producing the equilibria given in Scheme I.

Experimental Section

^1H NMR spectra were obtained with a Varian Associates HA-100 spectrometer; chemical shifts are expressed as parts per million (δ) downfield from internal or external tetramethylsilane. Electron ionization mass spectra were obtained with a CEC Du Pont Model 21-110B or Du Pont Model 21-491B mass spectrometer, and a modified Hitachi RMU6 mass spectrometer was used to obtain field desorption mass spectra. Ultraviolet spectra were obtained with a Cary 15 spectrophotometer. Melting points were determined on a microscope hot stage and are uncorrected. Titrations were performed using a Radiometer pHM62 pH meter.

Method[7] for Titration of Dimethyl- or Diethyl(1*H*-indol-3-yl)sulfonium Salts (4 or 6). The appropriate sulfonium salt (0.4 mmol) in 80 mL of methanol at room temperature was manually titrated with 0.100 N standard NaOH and plotted against pH. Back-titration was then carried out with 0.100 N standard HCl. See Figure 1 for experimental results.

^1H NMR Study of Sulfonium Salts 4 or 6 in Protic Solvents. A sulfonium salt (4 or 6) was dissolved in D_2O–trifluoroacetic acid (10:1) in a 5-mm tube containing a capillary tube of tetramethylsilane as an external standard. The tube was warmed in a water bath for 1 h. When the sample was cooled, two layers formed. The top (D_2O) layer was removed and the bottom viscous oily residue was redissolved using CD_3OD. ^1H NMR spectra were recorded at each step. Data from this study are contained in Figure 2 and Table II.

Titration and Mass Spectrometric Analyses of the Products Formed By Warming Aqueous Trifluoroacetic Acid Solutions of Sulfonium Salts 4 and 6. The products were prepared as described for the ^1H NMR study and subjected to acid–base titration (Figure 1) or mass spectrometric analysis (Table IV) as described.

Dimethyl(1*H*-indol-3-yl)sulfonium Iodide (4a, X = I). 3-(Methylthio)indole (**3a**,[1,3] 1.4 g, 8.5 mmol) and methyl iodide (1.2 g, 8.5 mmol) were mixed and left standing in a sealed vessel at room temperature for 24 h. The colorless crystals which formed were filtered and washed with ether to yield 2.6 g of **4a**, (98.8%), mp 125–127 °C (lit.[1] mp 131–133 °C).

3-(Dimethylsulfonio)indolide (1a)[1]. Sulfonium iodide **4a** (1.9 g, 6.2 mmol) in 5 mL of dimethylformamide was added to a suspension of sodium hydride in ether at 0 °C under a nitrogen atmosphere and the mixture was stirred for 2 h. The resulting colorless precipitate was triturated with 400 mL of chloroform. The undissolved residue was removed by filtration and discarded. The residue obtained by evaporation of the chloroform extract in vacuo at or below 20 °C yielded colorless crystals upon addition of ether. The collected product was recrystallized from $CHCl_3$/ether to yield 0.92 g (85%) of **1a**, mp 125–129 °C (lit.[1] mp 125 °C).

***S*-(2-Methyl-3-indolyl)isothiouronium Iodide.** To a vigorously stirred solution of 2-methylindole (3.93 g, 0.03 mol) and thiourea (2.28 g, 0.03 mol) in 250 mL of methanol and water (2:1) was added a potassium iodide–iodine (4.98 g, 0.03 mol; 7.61 g, 0.03 mol) solution in 70 mL of methanol and water (2:1). The mixture was stirred (0.5 h) until the solution turned yellow in color. The solution was then concentrated in vacuo to remove methanol and extracted with ethyl acetate. The remaining aqueous solution on further concentration in vacuo yielded light pink crystals which were collected and recrystallized from water to give 9.6 g (96%) of *S*-(2-methyl-3-indolyl)isothiouronium iodide, mp 194–197 °C dec.

3-(Methylthio)-2-methylindole (3b).[4] The isothiouronium salt (6.0 g, 0.018 mol), prepared in the previous experiment, in 100 mL of water was purged with nitrogen while heated on a steam bath. A sodium hydroxide solution (2 N, 100 mL), also purged with nitrogen with heating (0.5 h), was rapidly poured into the isothiouronium salt solution. With continued nitrogen purging, the mixture was heated on the steam bath for another 0.5 h. The resulting solution was placed in an ice bath and dimethyl sulfate (2.77 g, 0.022 mol) was added. After 1 h, the reaction mixture was extracted with 500 mL of dichloromethane. The extract was washed with water (2 × 100 mL) and dried over sodium sulfate, and the solvent was removed in vacuo. The resulting oily residue was distilled at reduced pressure to give 2.55 g (80%) of 3-(methylthio)-2-methylindole (**3b**), bp 107–110 °C (0.01 mmHg) (lit.[4] bp 140–142 °C (0.85 mmHg)).

Dimethyl(2-methyl-1*H*-indol-3-yl)sulfonium Iodide (4b, X = I). Methyl thioether **3b** (3.24 g, 0.018 mol) and methyl iodide (2.85 g, 0.02 mol) were mixed and allowed to stand in a tightly stoppered vessel for 24 h. The colorless needle-shaped crystals which formed were filtered and washed with ether to yield 4.99 g (85.5%) of **4b**, mp 134–136 °C. For characterizing data see the figures and tables and ref 2.

3-(Dimethylsulfonio)-2-methylindolide (1b). A mixture of ion-exchange resin (5 mL, Bio-Rad AG1-X8, 100–200 mesh in OH^- form, in methanol) and sulfonium iodide **5b** (1.88 g, 5.9 mmol) in methanol was stirred for 2.5 h. The ion-exchange resin was removed by filtration and washed with chloroform. The combined solvent was removed in vacuo at or below 20 °C to yield needle-shaped pale-yellow crystals which were collected and recrystallized from chloroform/hexane to give 1.2 g of **1b** (100%), mp 70–75 °C. For characterizing data see figures and tables and ref 2.

---

(22) This criterion is less than satisfactory for ruling out the occurrence of tautomers such as 7 since the covalent hydrate structures assigned (see following discussion) are similarly unsupported in that a resonance assignable to C-2 H was not observed.

(23) A. Albert, *J. Chem. Soc.*, 2690 (1955).

(24) A. Albert, D. J. Brown, and H. C. S. Wood, *J. Chem. Soc.*, 2066 (1956).

(25) A. Albert and W. L. F. Armarego, *Adv. Heterocycl. Chem.*, 4, 1 (1965).

(26) D. D. Perrin, *Adv. Heterocycl. Chem.*, 4, 43 (1965).

Dimethyl(2-phenyl-1*H*-indol-3-yl)sulfonium Chloride (4c). Freshly recrystallized (from benzene) 2-phenylindole (12 g, 0.062 mol) was dissolved in 75 mL of tetrahydrofuran, and dimethyl sulfoxide (5 mL, 0.070 mol) was added. The reaction flask was placed in an ice bath, and a slow stream of hydrogen chloride gas was passed through the reaction mixture until no further precipitation was observed. The precipitate was filtered and washed with toluene to produce 12.5 g of **4c** (69%) as a light gray powder, mp 148–151 °C (lit. mp 158–160 °C).

3-(Methylthio)-2-phenylindole (3c). Sulfonium chloride **4c** (2.45 g, 8.5 mmol) was heated under nitrogen at 130–150 °C for 1 h to give a dark-purple oily substance. This crude product was chromatographed on a 50-g silica gel column using benzene for elution. Pale-yellow crystals formed after evaporation of the benzene in vacuo and addition of carbon tetrachloride/hexane. The product was filtered and washed with hexane to yield 1.6 g of **3c** (81.2%), mp 97–100 °C (lit.[6] mp 106–107 °C).

3-(Dimethylsulfonio)-2-phenylindolide (1c). To sulfonium chloride **4c** (1.07 g, 3.7 mmol) in 30 mL of methanol was added 5 g of ion-exchange resin (Bio-Rad, AG1-X8, 100–200 mesh in OH^- form). The mixture was stirred at room temperature for 1 h. The ion-exchange resin was filtered and washed with chloroform, and the combined solvent was removed in vacuo at 20 °C or below. Pale-yellow crystals formed upon the addition of ether. The collected product **1c** was recrystallized from $CHCl_3$/ether to yield 0.82 g (87%) of **1c**, mp 148–151 °C (lit.[6] mp 165–169 °C). For characterizing data see the figures and tables and ref 2.

Diethyl(1*H*-indol-3-yl)sulfonium Iodide (6, X = I). To 1.77 g (10 mmol) of 3-(ethylthio)indole[27,28] in 0.25 mL of dimethylformamide was added 1.75 g (11 mmol) of ethyl iodide. The container was tightly stoppered and allowed to stand for 2 weeks. Ether was added to precipitate the product which was filtered and washed well with ether: 1.2 g (36%), mp 108–110 °C. For characterizing data see the figures and tables.

3-(Diethylsulfonio)indolide (5). To sulfonium iodide **6**, 0.5 g in 10 mL of methanol, was added 2.5 g of ion-exchange resin (Bio-Rad, AG1-X8, 100–200 mesh in OH^- form) in 10 mL of methanol. The mixture was stirred at room temperature for 1 h. The ion-exchange resin was removed by filtration and washed with dichloromethane. The combined organic solvent was removed in vacuo at 20 °C and the resulting solid was triturated with dichloromethane. Hexane was added to the dichloromethane-soluble portion to the cloud point. After standing for 2 h, the resulting colorless crystals were filtered to yield 0.2 g (76%) of 3-(diethylsulfonio)indolide (**5**), mp 68–71 °C. For characterizing data see the figures and tables.

Acknowledgment. We thank Professor Adrian Albert, University of Canberra, for helpful discussions during the course of this work.

Registry No. 1a, 54087-15-9; **1b**, 68996-46-3; **1c**, 56656-05-4; **3a**, 40015-10-9; **3b**, 40015-18-7; **3c**, 40015-25-6; **4a** (X = I), 54087-14-8; **4b** (X = I), 72610-11-8; **4c** (X = I), 72610-12-9; **4c** (X = Cl), 56656-03-2; **5**, 72610-13-0; **6** (X = I), 72610-14-1; 2-methylindole, 95-20-5; thiourea, 62-56-6; *S*-(2-methyl-3-indolyl)isothiouronium iodide, 72610-15-2; 2-phenylindole, 948-65-2; dimethyl sulfoxide, 67-68-5; ethyl iodide, 75-03-6; 3-(ethylthio)indole, 1484-16-8.

[27] R. V. Jardine and R. K. Brown, *Can. J. Chem.*, **43**, 1293 (1965).

[28] K. Tomita, A. Terada, and R. Tachikawa, *Heterocycles*, **4**, 729 (1976).

Photoinduced Decomposition of Peracetic Acid in Xylenes. Orientation in Aromatic Substitution of Methyl and Hydroxyl Radicals[1]

Yoshiro Ogata* and Kohtaro Tomizawa

Department of Applied Chemistry, Faculty of Engineering, Nagoya University, Chikusa-ku, Nagoya, Japan

Received July 17, 1979

The photolysis of peracetic acid (1) in *o*-, *m*- or *p*-xylenes (2) has been carried out using 2537-Å or >2900-Å light at 20–22 °C. The yields of ethyltoluenes (3), trimethylbenzenes (4), and dimethylphenols (6) are higher at 2537-Å than those at >2900-Å photolysis, but the reverse is true with the yield of methylbenzyl alcohol (5). The isomer distribution of trimethylbenzenes (4) formed from *o*- (**2a**) or *m*-xylene (**2b**) suggests that an attack of methyl radical at the position meta to the methyl group is favored with 2537-Å light, while an attack at the ortho position is preferential with >2900-Å light. On the other hand, the isomer distribution of dimethylphenols (6) at 2537 Å suggests that an attack of hydroxyl radical is favored at positions ortho and para to the methyl group. These orientations of radical attack are briefly discussed.

In the gas-phase photolysis of azomethane in toluene, methyl radical may abstract a hydrogen atom from the methyl group and/or add to the ring, ethylbenzene being a major nongaseous product in this system. On the other hand, in the liquid phase photolysis, *o*-xylene is a major product.[2] As we reported previously, the photolysis of peracetic acid in toluene with 2537-Å light gives xylenes in the order meta > ortho > para and ethylbenzene as major products, but the photolysis with >2900-Å light gives benzyl alcohol as a major product along with xylenes in the order ortho > meta > para,[3] which is consistent with that in the thermal decomposition of acetyl peroxide[4] and di-*tert*-butyl peroxide.[5]

The activation energy for hydrogen atom abstraction on the side chain of xylenes by methyl radical formed from acetone was reported to be 7.4 ± 0.2 for *p*-xylene, 7.8 ± 0.3 for *o*-xylene, and 8.5 ± 0.3 kcal/mol for *m*-xylene at 100–200 °C.[6] The difference was explained by the hyperconjugation effect in *p*- and *o*-xylenes.

We discuss in the present paper the effects of hyperconjugative electron release and wavelength of light on the

---

[1] Contribution No. 263.

[2] Cher, M. *J. Phys. Chem.* **1964**, *68*, 1316.

[3] Ogata, Y.; Tomizawa, K. *J. Org. Chem.* **1978**, *43*, 261.

[4] Eliel, E. L.; Rabindran, K.; Wilen, S. H. *J. Chem. Soc.* **1957**, 859.

[5] Cowley, B. R.; Norman, R. O. C.; Waters, W. A. *J. Chem. Soc.* **1959**, 1799.

[6] Sanders, W. A.; Rebbert, R. E. *J. Phys. Chem.* **1963**, *67*, 170.

0022-3263/80/1945-0785$01.00/0