Preparation and Characterization of Destructible Surfactants

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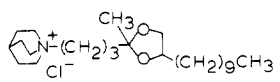
Surfactants have been designed and prepared specifically for the application of surfactant-based media to organic synthesis. Condensation of 5-chloro-2-pentanone with 1,2-dodecanediol (**3**) yielded 2-methyl-2-(3-chloropropyl)-4-decyl-1,3-dioxolane (**6**), which on reaction with quinuclidine and pyridine gave 1-[3-(4-decyl-2-methyl-1,3-dioxolan-2-yl)propyl]-1-azoniabicyclo[2.2.2]octane chloride (**1**) and 1-[3-(4-decyl-2-methyl-1,3-dioxolan-2-yl)propyl]pyridinium chloride (**2a**), respectively. Ketal-based surfactants **1** and **2a** are stable under neutral and basic conditions but readily hydrolyze under acidic conditions to 1-(4-oxopentyl)-1-azoniabicyclo[2.2.2]octane chloride (**4**) and 1-(4-oxopentyl)pyridinium chloride (**5**), respectively, and diol **3**. In catalysis of the potassium permanganate oxidation of piperonal to piperonylic acid and the aqueous sodium hydroxide hydrolysis of α,α,α-trichlorotoluene to benzoic acid, surfactants **1** and **2a** are about as effective as cetyltrimethylammonium bromide.

Surfactants have been used only infrequently in synthetic organic chemistry to catalyze reactions of water-insoluble substrates with water-soluble reagents.[1] In part, this is due to the fact that systems containing surfactants often form emulsuions that preclude reaction mixture workup by standard extraction procedures. However, the application of micellar, inverse micellar, microemulsion, and other surfactant-based media in synthetic organic chemistry warrants investigation because each of the commonly used methods for effecting reaction of a water-insoluble organic substrate with a water-soluble reagent (i.e., rapid stirring, cosolvent, dipolar aprotic solvent, phase-transfer catalysis) has its unique limitations.[2]

Results and Discussion

We have therefore prepared **1** and **2a** as the first examples of surfactants designed specifically for the application of surfactant-based media to organic synthesis.[3] Both **1** and **2a** contain a ketal group, which is stable under neutral and basic conditions but labile under acidic conditions.



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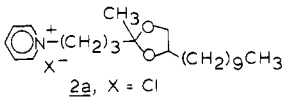
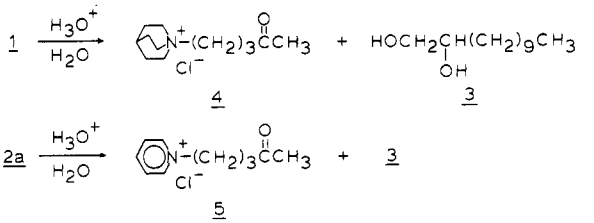


2a, X = Cl
2b, X = ClO_4
2c, X = PF_6

Hydrolysis of **1** and **2a** yields keto ammonium chlorides **4** and **5**, respectively, and 1,2-dodecanediol (**3**). Thus, surfactants **1** and **2a** can be used to catalyze reactions, and subsequent acidification during workup converts them to nonsurfactant products, thereby eliminating any emulsion problem and facilitating the use of straightforward extraction procedures.[4]

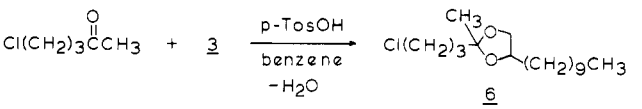
Surfactants **1** and **2a** were prepared as follows. The *p*-toluenesulfonic acid catalyzed condensation of diol **3** with



4 **3**

5

5-chloro-2-pentanone in refluxing benzene under a Dean–Stark trap yielded chloro ketal **6**, which on reaction with



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excess quinuclidine in refluxing absolute ethanol yielded **1**.[5] Ethanol was removed from the reaction mixture by rotary evaporation and excess quinuclidine by sublimation at 90 °C (0.05 mmHg) to leave the hemihydrate of **1** as a hygroscopic white solid, mp 177–180 °C. By ^1H NMR analysis this material consisted of two diastereomers that correspond to cis and trans isomers with respect to the five-membered ring. Chloro ketal **6** was converted to **2a** in refluxing pyridine, and removal of excess pyridine left **2a** as a hygroscopic semisolid that likewise consisted of two diastereomers by ^1H NMR analysis. For characterization by combustion analysis, **2a** was converted to **2b** and **2c** by the addition of aqueous solutions of sodium perchlorate and potassium hexafluorophosphate, respectively, to dilute aqueous ammonia solutions of **2a**. Compounds **2b** and **2c** are amorphous nonhygroscopic solids which can be recrystallized from ethyl acetate–hexane. Interestingly, similar treatment of **1** with sodium perchlorate and potassium hexafluorophosphate yielded perchlorate and hexafluorophosphate analogues of **1** as oils.

Keto ammonium chlorides **4** and **5** were prepared by procedures analogous to those used for synthesis of **1** and **2a**. Compound **4** is a crystalline solid obtained as the hemihydrate, and **5** is a deliquescent solid which was converted to the hexachloroplatinate for characterization. An alternative synthesis of **2a** by *p*-toluenesulfonic acid catlayzed condensation of **5** with diol **3** in benzene was less satisfactory than that above since it gave **2a** contaminated with **3** and **5**.

Plots of surface tension vs. concentration in 0.01 M sodium bicarbonate for both surfactants **1** and **2a** displayed

(1) For examples, see: (a) Menger, F. M.; Rhee, J. U.; Rhee, H. K. *J. Org. Chem.* **1975**, *40*, 3803. (b) Link, C. M.; Jansen, D. K.; Sukenik, C. N. *J. Am. Chem. Soc.* **1980**, *102*, 7798.

(2) Rapid stirring works well with only a few inorganic reagents, and a cosolvent may undesirably participate in a reaction. Product isolation from a dipolar aprotic solvent can be difficult, and in large-scale operations the cost of the solvent may be prohibitive. Phase-transfer catalysis is generally restricted to nucleophilic and base-catalyzed reactions and can suffer from catalyst deactivation (Dehmlow, E. V. *Angew. Chem., Int. Ed. Engl.* **1974**, *13*, 170).

(3) Keana and co-workers (Cuomo, J.; Merrifield, J. H.; Keana, J. F. W. *J. Org. Chem.* **1980**, *45*, 4216) have prepared and characterized destructible nonionic surfactants (unsymmetrical aryl glucosyl disulfides) for use in membrane protein isolation and purification.

(4) The organic product must be separated from the hydrolysis products, however. An acidic or basic product can be separated from diol **3** and **4** (**5**) simply by appropriate extractions. A neutral organic product would be separated from **3** by other methods such as distillation or chromatography.

(5) Triethylamine was used first in an attempt to incorporate a quaternary ammonium head group. However, chloro ketal **6** was unreactive in refluxing triethylamine and in refluxing triethylamine–ethanol, most likely due to steric effects.

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Table I. Potassium Permanganate Oxidations of Piperonal to Piperonylic Acid at 50-60 °C[a,b]

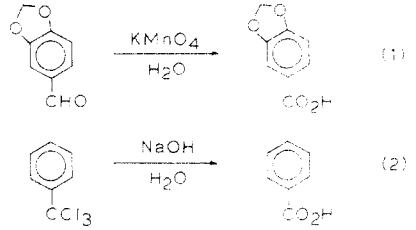
run	surfactant	% yield of piperonylic acid
1	1	45[c]
2	1	52[c]
3	1	64
4	CTABr	50[c] (65)[d]
5	none	26[c] (37)[d]

[a] Aqueous $KMnO_4$ was added dropwise to a heterogeneous mixture of piperonal and water containing 0.01 M surfactant, if used; see the Experimental Section for details. [b] The reaction time was uniformly 2.5 h. [c] Runs 1 and 5 were performed simultaneously as a pair in the same oil bath as were runs 2 and 4. [d] Results in parentheses are from analogous runs at 55 °C in ref 1a.

slight hysteresis that precluded determination of precise critical micelle concentration (CMC) values. However, the CMC's of 1 and **2a** are estimated to be 2 and 1×10^{-3} M, respectively. The surface tension of both 1 and **2a** solutions above their CMC's was approximately 38 dynes/cm, as compared to about 41 dynes/cm for analogous solutions of cetyltrimethylammonium bromide (CTABr). Thus 1 and **2a** display the surface activity expected of cationic surfactants.

In a demonstration of the destructible character of these surfactants, a mixture of **1**, 5% hydrochloric acid, and ether was shaken in a separatory funnel. It gave an emulsion immediately after its preparation, but within 15 min the ether and aqueous layers rapidly separated without foaming after shaking. In an analogous experiment with the substitution of 1% hydrochloric acid, rapid separation of layers after shaking occurred within 1 h, and diol **3** was isolated in 99% yield.

Ketal-based surfactants 1 and **2a** have been used to catalyze two reactions, the potassium permanganate oxidation of piperonal to piperonylic acid (eq 1) and the hydrolysis of α,α,α-trichlorotoluene to benzoic acid in aqueous sodium hydroxide (eq 2). Since Menger and coworkers[1a] have previously studied the ability of CTABr and other materials to catalyze these reactions, comparison of the present with prior results allowed a rough calibration of the catalytic efficacies of 1 and **2a**. Both reactions 1 and 2 were performed under heterogeneous conditions with aqueous and organic phases present, and results are summarized in Tables I and II, respectively.



In Table I, the yields of piperonylic acid obtained with 1 in runs 1–3 varied considerably. However, taken as a whole, the data clearly indicate that 1 is as effective as CTABr in catalysis of the oxidation. Note that in simultaneous runs 2 and 4 with 1 and CTABr, respectively, essentially the same yield of piperonylic acid was obtained. Furthermore, comparison of runs 1–4 with run 5 indicates that the oxidation benefits substantially from surfactant catalysis; note that runs 1 and 5 were performed simultaneously.

The workup procedure for runs 1–5 is given here to allow illustration of the benefits of the destructible character of **1**: (a) basification of the reaction mixture with aqueous sodium hydroxide and filtration to remove manganese dioxide, (b) extraction with ether to remove unreacted piperonal, (c) acidification with hydrochloric acid and extraction of piperonylic acid with ether, (d) extraction of the ether extracts with aqueous sodium hydroxide, and (e) acidification of the aqueous extracts with hydrochloric acid to precipitate piperonylic acid. In step b, only with CTABr did an emulsion develop, which broke after 30 min. In step c, the system with 1 gave copious amounts of foam before and immediately after acidification but within 15 min no longer foamed on shaking. Extraction with ether followed in a straightforward manner without emulsion formation. In step c with CTABr, the foaming persisted after acidification, and an emulsion formed during ether extraction which broke completely only after 1.5 h. In step d for run 2, diol **3** was recovered in 68% yield from the ether layer after the sodium hydroxide extraction, which indicates that the ketal function is stable to the oxidation conditions. The other hydrolysis product, **4**, was not isolated from the acidified aqueous layer of step c, but the foaming in this step indicated that the quinuclidinium head group was intact.

Table II. Hydrolyses of α,α,α-Trichlorotoluene in Aqueous 20% Sodium Hydroxide at 80-90 °C

	additive			
run	nature	concn, M	rctn time, h[a]	% yield of benzoic acid
6	1	0.01	6.5[b]	94
7	1	0.01	9.3	91
8	**2a**	0.01	7	91
9	**2a**	0.01	10[b]	90
10	CTABr	0.01	2[b] (1.5)[c]	93 (98)[c]
11	none		(60)[c]	(97)[c]
12	n-$Bu_4N^+Br^-$	0.02	(15)[c]	(98)[c]

[a] The time required for completion of the reaction as evidenced by disappearance of the organic phase. [b] Runs 6, 9, and 10 were performed simultaneously in the same oil bath. [c] Results in parentheses are from analogous runs at 80 °C in ref 1a.

The data of Table II indicate that as catalysts for the hydrolysis, surfactants 1 and **2a** were less effective than CTABr but more so than tetra-n-butylammonium bromide (run 12), a typical phase-transfer catalyst. The workup procedure included: (a) extraction with ether, (b) acidification with hydrochloric acid and extraction of benzoic acid with ether, (c) extraction of the ether extracts with aqueous sodium hydroxide, and (d) acidification of the aqueous extracts with hydrochloric acid to precipitate benzoic acid. In step a, emulsions formed only with 1 and CTABr that both broke after 30 min. In step b, an emulsion formed only with CTABr that broke after 10 min, and in step c, diol **3** was recovered in 71% yield from the ether layer after sodium hydroxide extraction in run 6. In runs 8 and 9, the aqueous reaction mixtures contained small amounts of a red-brown oil on their surfaces after the indicated times, most likely indicating that **2a** underwent at least partial decomposition. Nevertheless, it effected complete disappearance of α,α,α-trichlorotoluene in times considerably less than the 60 h required without any catalyst (run 11).

It is not clear at present whether 1 and **2a** are functioning by phase-transfer and/or micellar-emulsion catalysis. In his study of the catalysis of the same reactions by CTABr and Brij 35 [$C_{12}H_{25}(OCH_2CH_2)_{23}OH$], Menger concluded[1a] that the latter was more likely. We are currently preparing additional examples of destructible surfactants based on other functionalities and are surveying their applications.

Experimental Section

General Procedures. All melting and boiling points are uncorrected. The ^1H NMR spectra were obtained with a Varian HA-100 spectrometer, and $CDCl_3$ was used as solvent with Me_4Si as internal standard unless noted otherwise. Infrared spectra were recorded on a Beckman Model IR-10 spectrophotometer with neat or Nujol mull samples between NaCl plates. Mass spectra were recorded on a Varian MAT CH-5 spectrometer with an ionizing voltage of 70 eV and direct insertion. For thin-layer chromatography analysis of **1** and **2a**, 5 × 20 cm glass plates coated with 0.25 mm of aluminum oxide containing a fluorescent indicator were used with 10% (v/v) ether (washed with dilute aqueous ammonia)–hexane as eluant. Microanalyses were performed by Atlantic Microlab, Atlanta, GA.

Critical Micelle Concentrations. The CMC values in 0.01 M $NaHCO_3$ were determined at room temperature by the du Noüy ring method with a Cahn Model RM-2 electrobalance and Cahn Model 2370 surface tension accessory. For **1**, relative surface tension measurements were made for the following concentrations: 3.88, 2.80, 2.25, 1.68, 1.23, 0.840, and 0.336 × 10^{-3} M. The plot of relative surface tension vs. concentration displayed slight hysteresis, and the CMC was approximately 2 × 10^{-3} M. For **2a**, relative surface tension measurements were made for the following concentrations: 4.6, 3.7, 2.9, 1.8, 1.1, 0.74, 0.56, 0.44, 0.37, 0.28, and 0.14 × 10^{-3} M. The plot of relative surface tension vs. concentration displayed hysteresis, and the CMC was approximately 1 × 10^{-3} M. The relative surface tension (400) for the 1.8 × 10^{-3} M solution was the same after 29 h, as was that (613) for the 0.28 × 10^{-3} M solution after 32 h. After 132 days the value for the 4.6 × 10^{-3} M solution decreased slightly from 457 to 433. The relative surface tension for 0.01 M $NaHCO_3$ was 925.

2-Methyl-2-(3-chloropropyl)-4-decyl-1,3-dioxolane (6). The 1,2-dodecanediol (mp 59–60 °C, lit.[6] mp 60–61 °C) was prepared[6] from 1-dodecene (Aldrich). For preparation of **6** a general procedure[7] was used. A round-bottomed flask was equipped with a Dean–Stark trap fitted with a reflux condenser bearing a drying tube ($CaCl_2$). A mixture of 25.0 g (0.124 mol) of diol **3**, 12.6 g (0.105 mol) of 5-chloro-2-pentanone (Aldrich), 0.166 g (0.874 mmol) of *p*-toluenesulfonic acid monohydrate, and 60 mL of benzene was refluxed for 19.5 h; about 1.5 mL of water collected in the Dean–Stark trap. The benzene was rotary-evaporated and the residue dissolved in 200 mL of $CHCl_3$. The resulting solution was washed with 200 mL each of aqueous 5% $NaHCO_3$, H_2O, and saturated aqueous NaCl and dried over $MgSO_4$. Rotary evaporation left 33.7 g of crude **6** as a red-brown oil which was purified by two methods. In the first, 0.50 g of it was filtered through a 1.7 (i.d.) × 28 cm column of neutral alumina (pH 7.4), using 10% (v/v) ether–hexane as eluant to give 0.48 g of **6** as a clear, colorless oil which solidified at −10 °C. In the second method, a mixture of 4.72 g of crude material and 25 mL of ice-cold hexane was filtered to remove undissolved solids, and the filtrate was rotary-evaporated to give 3.67 g of a red-brown oil which was distilled to yield 2.72 g of **6** as a colorless oil plus a white wax: bp 122–123 °C (0.06 mmHg); ^1H NMR δ 3.87–4.06 (m, 2 H, OCH_2), 3.33–3.58 (m, 3 H, CH_2Cl and OCH), 1.77 (br s, 4 H, $CH_2CH_2CH_2Cl$), 1.10–1.68 (m, 21 H, $OCCH_3$ and $(CH_2)_9$), 0.84 (t, 3 H, CH_3) [within the δ 1.10–1.68 multiplet there were three distinct singlets at δ 1.30, 1.26, and 1.23; the first two correspond to the CH_3 groups of the two diastereomers and the other to $(CH_2)_9$]; mass spectrum, *m/e* (% base) 291 (11), 289 (30), 227 (100); IR (neat) 2920 (s), 2860 (s), 1460 (m), 1373 (m), 1305 (w), 1245 (m), 1118 (m), 1050 (m), 880 cm^{-1} (m). As is characteristic of ketals, the mass spectrum did not contain a peak corresponding to M^+·; the peaks at *m/e* 289/291 correspond to the loss of CH_3 and that at 277 to the loss of CH_2CH_2Cl. The IR spectrum contained no C=O band, indicating the absence of 5-chloro-2-pentanone.

Preparative GLC (190 °C; He; 6 ft × 0.25 in. aluminum column packed with 4% SE-30 on 60–80-mesh AW-DMCS Chromosorb W) gave an analytical sample. Anal. Calcd for $C_{17}H_{33}ClO_2$: C, 66.97; H, 10.91. Found: C, 67.08; H, 10.87.

1-[3-(4-Decyl-2-methyl-1,3-dioxolan-2-yl)propyl]-1-azoniabicyclo[2.2.2]octane Chloride (1). All glassware was oven-dried. A mixture of 1.03 g (3.38 mmol) of chloro ketal **6**, 0.959 g (8.62 mmol) of quinuclidine (Aldrich), and 10.0 mL of absolute C_2H_5OH was refluxed for 24 h under N_2 and then rotary evaporated with a drying tube ($CaCl_2$) between the water aspirator and system. The resultant oil was held at 90 °C (0.05 mmHg) for 3 h to give 1.40 g (97%) of white solid **1**: mp 177–180 °C; ^1H NMR δ 3.86–4.12 (m, 2 H, OCH_2), 3.32–3.86 (m, 9 H, OCH and NCH_2), 1.88–2.24 (m, 7 H, CH_2 at C-3, C-5, C-8, and CH of quinuclidinium), 1.00–1.88 (m, 25 H, $CH_2CH_2CH_2N$, $OCCH_3$, and $(CH_2)_9$), 0.86 (t, 3 H, CH_3) [the δ 1.00–1.88 region contained a large singlet at δ 1.24, corresponding to $(CH_2)_9$, and shoulders at 1.26 and 1.31, corresponding to $OCCH_3$ singlets for the two diastereomers]; IR (neat) 3275 (m), 2925 (s), 2860 (s), 1463 (m), 1370 (m), 1325 (w), 1275 (w), 1240 (m), 1145 (m), 1070 (s), 1040 (m), 955 (w), 885 (m), 830 cm^{-1} (m). The broad band at 3275 cm^{-1} corresponds to absorbed water; no C=O band was observed. Anal. Calcd for $C_{24}H_{46}ClNO_2 \cdot 0.5H_2O$: C, 67.81; H, 11.15. Found: C, 67.96, 67.87; H, 11.18, 11.20.[8]

With procedures similar to those used to form **2b** and **2c** from **2a** (vide infra), the perchlorate and hexafluorophosphate analogues of **1** were prepared. Since they were amorphous and easily formed oils, their purification and characterization were not attempted.

1-(4-Oxopentyl)-1-azoniabicyclo[2.2.2]octane Chloride. Technical grade 5-chloro-2-pentanone (Aldrich) was purified by gravity filtration through neutral alumina (pH 7.4). A mixture of 0.582 g (4.83 mmol) of purified 5-chloro-2-pentanone, 0.989 g (8.89 mmol) of quinuclidine, and 10.0 mL of absolute C_2H_5OH was refluxed for 25.5 h under N_2 and rotary-evaporated. The resultant 1.26 g of yellow-brown solid was held at 90 °C (0.05 mmHg) for 4.5 h to give 1.02 g (91%) of crude **4**. A boiling acetone solution of this material was decolorized 3 times with fresh portions of Norit, concentrated to 25 mL, diluted with 25 mL of ethyl acetate, and cooled to −10 °C. The resulting needles, 0.546 g, were recrystallized from acetone–ethyl acetate at −10 °C to give 0.400 g of **4**: mp 98–99 °C; ^1H NMR δ 3.16–3.84 (m, 8 H, NCH_2), 2.63 (t, J = 6 Hz, 2 H, CH_2CO), 1.78–2.26 (s at 2.12 overlapping with m, 12 H total, CH_3CO, CH_2 at C-3, C-5, C-8, and CH of quinuclidinium and $CH_2CH_2CH_2N$). Anal. Calcd $C_{12}H_{22}ClNO \cdot 0.5H_2O$: C, 59.86; H, 9.63. Found: C, 59.84, 59.79; H, 9.65, 9.66.

1-[3-(4-Decyl-2-methyl-1,3-dioxolan-2-yl)propyl]-pyridinium Chloride (2a). All glassware was oven-dried. A mixture of 0.855 g (2.80 mmol) of chloro ketal **6** and 10.0 mL of pyridine (distilled from BaO) was refluxed for 22 h under a drying tube ($CaCl_2$). Rotary evaporation with a drying tube between the water aspirator and system left an oil which contained traces of pyridine that were removed under vacuum (0.05 mmHg) at 25 °C to give 1.01 g (94%) of amorphous hygroscopic **2a**: ^1H NMR δ 9.58–9.81 (m, 2 H, 2-pyridinium), 8.40–8.68 (m, 1 H, 4-pyridinium), 8.06–8.32 (m, 2 H, 3-pyridinium), 5.05 (br t, J = 7 Hz, 2 H, CH_2N), 3.81–4.12 (m, 2 H, OCH_2), 3.19–3.56 (m, 1 H, OCH), 1.93–2.35 (m, 2 H, $CH_2CH_2CH_2N$), 1.04–1.84 (m, 23 H, $CH_2CH_2CH_2N$, $OCCH_3$, and $(CH_2)_9$), 0.86 (t, 3 H, CH_3) [the δ 1.04–1.84 region contained a large singlet at 1.24 with a shoulder at 1.31, corresponding to $(CH_2)_9$ and $OCCH_3$; the aromatic region corresponded to overlap of signals for two diastereomers]; IR (neat) 3400 (s), 3030 (m), 2925 (s), 2855 (s), 1638 (s), 1485 (s), 1460 (m), 1375 (m), 1320 (w), 1210 (m), 1160 (m), 1050 (m), 880 (m), 770 (m), 680 cm^{-1} (m). The broad band at 3400 cm^{-1} corresponds to absorbed water; no C=O band was observed. After **2a** was stored 2.5 months at −10 °C it gave the same IR spectrum.

The hygroscopic, amorphous character of **2a** precluded its characterization by combustion analysis. Therefore, perchlorate and hexafluorophosphate analogues **2b** and **2c**, respectively, were prepared below.

1-[3-(4-Decyl-2-methyl-1,3-dioxolan-2-yl)propyl]-pyridinium Perchlorate (2b). To a solution of 321 mg (0.837 mmol) of **2a** in 2.5 mL of 3 M aqueous ammonia was added to a solution of 0.125 g (0.890 mmol) of $NaClO_4 \cdot H_2O$ in 1 mL of water. A brown precipitate formed, and addition of 0.134 g of $NaClO_4 \cdot H_2O$ to the mixture gave no perceptible additional precipitate. The solid was collected and dried at 25 °C (0.05 mmHg) for 3 h to give 252 mg (67%) of crude **2b**, which was recrystallized 3 times

(6) Swern, D.; Billen, G. N.; Scanlan, J. T. *J. Am. Chem. Soc.* **1946**, *68*, 1504.
(7) Brandman, H. A.; Conley, R. T. *J. Org. Chem.* **1973**, *38*, 2236.
(8) The weights, molar amounts, and concentrations indicated for **1** are for the hemihydrate.

at −10 °C from 75% (v/v) ethyl acetate (stored over K_2CO_3)–hexane to give **2b**: mp 63–65 °C. Anal. Calcd for $C_{22}H_{38}ClNO_6$: C, 58.98; H, 8.55. Found: C, 58.93; H, 8.57.

1-[3-(4-Decyl-2-methyl-1,3-dioxolan-2-yl)propyl]-pyridinium Hexafluorophosphate (2c). To a solution of 397 mg (1.04 mmol) of **2a** in 2 mL of 3 M aqueous ammonia was added a solution of 250 mg (1.34 mmol) of KPF_6 in 2 mL of water. A brown precipitate formed which was collected and dried at 25 °C (0.05 mmHg) to give 344 mg (67%) of crude **2c**, which was recrystallized 3 times at −10 °C from ethyl acetate (stored over K_2CO_3)–hexane to give **2c**, mp 68–70 °C. Anal. Calcd for $C_{22}H_{38}F_6NO_2P$: C, 53.54; H, 7.76. Found: C, 53.73; H, 7.80.

1-(4-Oxopentyl)pyridinium Chloride (5). A mixture of 1.05 g (8.71 mmol) of purified 5-chloro-2-pentanone and 10 mL of pyridine (distilled from BaO) was refluxed for 3 h under N_2. Rotary evaporation left an oil which contained traces of pyridine that were removed under vacuum (0.05 mmHg) at 25 °C to give 1.65 g (95%) of crude **5** as a tan deliquescent solid: ^1H NMR (Me_2SO-d_6 with external coaxial Me_4Si reference in $CDCl_3$) δ 9.55–9.69 (m, 2 H, 2-pyridinium), 8.75–8.97 (m, 1 H, 4-pyridinium, 8.29–8.51 (m, 2 H, 3-pyridinium), 4.98 (t, J = 7 Hz, 2 H, CH_2N), 2.85 (t, J = 7 Hz, 2 H, CH_2CO), 2.15–2.51 (s at 2.28 overlapping with p at 2.33, J = 7 Hz, 5 H total, CH_3CO and $CH_2CH_2CH_2N$). The deliquescent character of **5** precluded its characterization by combustion analysis. Therefore, it was converted to the corresponding hexachloroplatinate as described below.

1-(4-Oxopentyl)pyridinium Hexachloroplatinate. Addition of a C_2H_5OH solution of **5** to a C_2H_5OH solution of excess $H_2PtCl_6 \cdot 6H_2O$ immediately gave a yellow precipitate which was collected and recrystallized from aqueous C_2H_5OH to give 1-(4-oxopentyl)pyridinium hexachloroplatinate, mp 153–154 °C decomp. Anal. Calcd for $C_{20}H_{28}Cl_6N_2O_2Pt$: C, 32.62; H, 3.83. Found: C, 32.82; H, 3.87.

Hydrolyses of Surfactant 1. To a separatory funnel were added 134 mg of **1**, 90 mL of aqueous 5% (w/w) HCl, and 25 mL of ether. The mixture gave an emulsion on being shaken immediately after its preparation but within 15 min rapidly separated without foaming into ether and aqueous layers after being shaken. In an analogous experiment with 133 mg of **1**, 90 mL of aqueous 1% HCl, and 25 mL of ether, rapid separation after shaking of the ether and aqueous layers occurred within 1 h. After the mixture sat overnight at room temperature, the aqueous layer was extracted with two additional 25-mL portions of ether. The combined ether extracts were washed with 10 mL of saturated aqueous NaCl and dried over Na_2SO_4 to leave 62.5 mg (99%) of diol **3**, mp 57–59 °C.

Oxidations of Piperonal. Piperonal (Eastman) was recrystallized at −10 °C from aqueous C_2H_5OH to give material with a melting point of 35–36 °C (lit.[9] mp 37 °C). A modified procedure of Menger and co-workers[1a] was used for the oxidations. The descriptions below are for runs 2 and 4 of Table I with **1** and CTABr, respectively. Other runs were performed analogously. Two 100-mL three-necked round-bottomed flasks were equipped identically with magnetic stirring bars, addition funnels, and reflux condensers fitted with N_2 lines. To one flask were added 0.110 g (0.302 mmol) of CTABr (Aldrich), 1.00 g (6.67 mmol) of piperonal, and 25 mL of H_2O. To the other flask were added 0.124 g (0.291 mmol) of **1**, 1.00 g (6.67 mmol) of piperonal, and 25 mL of H_2O. The flasks were then placed in the same oil bath at 50–60 °C above a single magnetic stirring motor, and to each stirred reaction mixture was added dropwise a solution of 1.5 g (9.5 mmol) of $KMnO_4$ in 35 mL of H_2O during 30 min. Each mixture was then stirred at 50–60 °C for 150 min and filtered after the addition of 5 mL of aqueous 10% NaOH. In each filtration, the MnO_2 residue was washed with 50 mL of H_2O at 60 °C, and the wash was combined with the main filtrate and extracted with 50 mL of ether. The reaction mixture with **1** gave almost immediate phase separation, whereas the mixture with CTABr gave an emulsion which separated after 30 min. After separation of the ether layers, 40 mL of aqueous 10% HCl was added to each of the aqueous layers. Immediately thereafter, the mixture with **1** foamed on being shaken but after 15 min did not foam even with vigorous shaking. It was then extracted with two 50-mL portions of ether with no foaming or emulsion problem whatsoever. The combined ether extracts were extracted with two 15-mL portions of aqueous 5% NaOH, and the combined aqueous extracts were acidified with 20 mL of aqueous 10% HCl to precipitate piperonylic acid. The mixture was cooled to 0 °C and filtered; the resultant solid was washed with 25 mL of ice-cold H_2O to yield 0.579 g (52%) of piperonylic acid, mp 229–230 °C (lit.[10] mp 230–232 °C. The ether that was extracted with aqueous 5% NaOH above was dried 2 times over Na_2SO_4 to give 53.8 mg of a mixture of piperonal and diol **3** which by ^1H NMR analysis contained 40 mg of **3**, which corresponds to a 68% recovery from the hydrolysis of **1**.

On being shaken, the acidified mixture with CTABr from above foamed both immediately and 25 min after the HCl addition, when it was extracted with 50 mL of ether. An emulsion resulted which separated completely after 1.5 h. A second extraction with 50 mL of ether gave an emulsion which separated in 45 min. The combined ether extracts were extracted as above in the run with **1**, and further identical workup yielded 0.553 g (50%) of piperonylic acid, mp 229–230 °C.

Hydrolyses of α,α,α-Trichlorotoluene. The α,α,α-trichlorotoluene (Eastman) was purified by distillation to give material with bp 85–87 °C (ca. 20 mmHg). The procedures below are for runs 6, 9, and 10 with **1**, **2a**, and CTABr, respectively. Other runs were performed analogously. Three 100-mL round-bottomed flasks were equipped identically with magnetic stirring bars and reflux condensers fitted with N_2 lines. To the first flask was added 54.5 mg (0.150 mmol) of CTABr, to the second 63.6 mg (0.150 mmol) of **1**, and to the third 61.9 mg (0.161 mmol) of **2a**. Then 2.05 g (10.5 mmol) of α,α,α,-trichlorotoluene and 15 mL of 20% (w/w) aqueous NaOH were added to each flask. The three flasks were placed in a single oil bath at 80–90 °C over a single magnetic stirrer. The heterogeneous reaction mixtures were then stirred simultaneously, and when a mixture became homogeneous, indicating the end of the reaction, it was removed from the oil bath. The reaction times were 2, 6.5, and 10 h for the CTABr, **1**, and **2a** systems, respectively.

The mixture with CTABr was diluted with 25 mL of H_2O and extracted with 25 mL of ether. An emulsion resulted that broke after 30 min. Then the aqueous layer was acidified with 25 mL of aqueous 10% HCl and extracted with three 25-mL portions of ether. In each extraction an emulsion resulted that broke after ca. 10 min. The combined ether extracts were extracted with two 15-mL portions of aqueous 5% NaOH. The combined basic extracts were acidified with 25 mL of aqueous 10% HCl and extracted with three 25-mL portions of ether which were combined and dried over Na_2SO_4 to yield 1.20 g (93%) of benzoic acid, mp 119–121 °C.

The reaction mixture with **1** was diluted with 25 mL of H_2O and extracted with 25 mL of ether. An emulsion formed that broke after 30 min. Then the aqueous layer was acidified with 25 mL of aqueous 10% HCl and extracted with three 25-mL portions of ether with no emulsion problem. From here on the ether extracts were worked up as above to yield 1.20 g (93%) of benzoic acid, mp 119–121 °C. The ether layer after extraction with aqueous NaOH in this procedure was washed with three 25-mL portions of water and dried over Na_2SO_4 to leave 68.8 mg of an oil. This material was chromatographed on a 1.7 (i.d.) × 28 cm column of silica gel packed in hexane with 200-mL portions of 10, 20, 35, 45, and 55% (v/v) ether–hexane as eluant. Diol **3**, 21.4 mg, mp 53–55 °C, eluted with 45% ether–hexane; this corresponds to a 71% recovery from the hydrolysis of **1**.

At the end of the reaction period with **2a**, the mixture contained a few droplets of dark red-brown oil on its surface, perhaps from the at least partial decompositon of **2a**. The mixture was diluted with 25 mL of H_2O and extracted with three 25-mL portions of ether with no emulsion problem, and the aqueous layer was worked up as above with no emulsion problem to yield 1.15 g (90%) of benzoic acid, mp 119–121 °C.

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(9) Baker, W. *J. Chem. Soc.* **1931**, 1765.

(10) Gulland, J. M.; Macrae, T. F. *J. Chem. Soc.* **1932**, 2231.

Chemical Society, to the U.S. Army Research Office, and to the Marathon Oil Co. for support of this research.

Registry No. *cis*-1, 79722-23-9; *trans*-1, 79722-24-0; *cis*-**2a**, 79722-25-1; *trans*-**2a**, 79722-26-2; **2b**, 79722-28-4; **2c**, 79722-29-5; **3**, 1119-87-5; **4**, 79722-30-8; **5**, 79722-31-9; *cis*-**6**, 79722-32-0; *trans*-**6**, 79722-33-1; 5-chloro-2-pentanone, 5891-21-4; quinuclidine, 100-76-5; 1-(4-oxopentyl)pyridinium hexachloroplatinate, 79735-25-4; piperonal, 120-57-0; piperonylic acid, 94-53-1; 2,2,2-trichlorotoluene, 98-07-7; benzoic acid, 65-85-0.

Substituent Effect Behavior in the Antiaromatic Inden-1-yl Cation System

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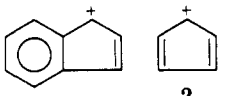
Studies of the rate-accelerating effects in solvolysis produced by 5-methyl and 5-methoxy substituents on the benzene ring and a 3-methyl substituent on the double bond of the inden-1-yl 3,5-dinitrobenzoate system have been carried out. In both 80% aqueous acetone and in 2,2,2-trifluoroethanol, the rate accelerations observed in the inden-1-yl system were approximately the same as those found in model cyclopenten-3-yl and indan-1-yl systems. From these results, it is concluded that delocalization of charge into both the benzene ring and double bond of the 8π-electron inden-1-yl carbocation is taking place and is apparently undiminished by antiaromatic effects.

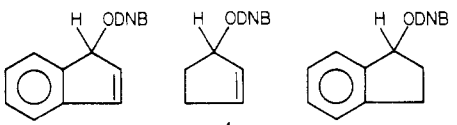
Introduction

Several years ago, we initiated a study[1] directed toward obtaining experimental information under normal solvolytic conditions concerning the structural and chemical consequences of potential antiaromaticity[2] in the 8π electron inden-1-yl cation system (1). Our interest in this



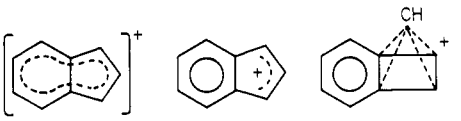
1 2

specific system was because of its close relationship to the classic 4π-electron cyclopentadienyl cation (2). However, in contrast to the latter,[3] its precursors are easier to handle and its formation requires somewhat less drastic conditions. Thus, the rates of solvolysis of inden-1-yl 3,5-dinitrobenzoate (3) and suitable model compounds including 4 and 5 were investigated in 80% aqueous acetone or in 2,2,2-trifluoroethanol. At 80 °C, 3 was found to be approximately 10^{11}-fold retarded in rate as compared to what would be predicted for the compound in the absence of destabilizing antiaromatic interactions in its activated complex for ionization.



3 4 5

We have now turned our attention toward obtaining evidence under solvolytic conditions of the structure of the inden-1-yl cation intermediate. For example, by analogy to similar questions which have been raised concerning the structure of the cyclopentadienyl cation 2,[4] is the inden-1-yl cation a completely delocalized ground-state triplet as in 6, a partially delocalized ground-state singlet as in 7, or possibly even a square-pyramidal species such as 8? For the case of the parent unsubstituted cyclopentadienyl cation 2 generated by treatment of 5-bromocyclopentadiene with SbF_5 at 78 K, EPR studies have shown[5] that it is a planar, regular pentagonal triplet in its ground state. The pentaphenylcyclopentadienyl cation, on the other hand, is a ground-state singlet.[6]



6 7 8

To obtain information as to the structure of the inden-1-yl cation we examined the effects upon its ease of formation of adding electron-releasing substituents on both the double bond and benzene ring sides of the molecule. It was anticipated that this should reveal the extent of charge delocalization at various positions in the activated complex leading to the inden-1-yl cation intermediate. For example, if the substituent causes a much smaller or no accelerating effect when compared to that observed in a suitable delocalized model system, then it can be concluded that diminished or no delocalization of charge at that carbon is occurring. The results of this study are described below.

Results and Discussion

For the study of the delocalization in the inden-1-yl cation system, it was necessary to prepare compounds 9, 10, and 11 for use in kinetic substituent effect comparisons with 3. Also, compounds 12, 13, and 14 were prepared as model systems whose kinetic behaviors were to be compared with 4 and 5 to assess the magnitudes of the substituent effects to be expected when normal charge delocalization is taking place.

(1) Friedrich, E. C.; Taggart, D. B. *J. Org. Chem.* **1978**, *43*, 805.
(2) Breslow, R. *Acc. Chem. Res.* **1973**, *6*, 393.
(3) Breslow, R.; Hoffman, J. M., Jr. *J. Am. Chem. Soc.* **1972**, *94*, 2110.
(4) (a) Breslow, R.; Mazur, S. *J. Am. Chem. Soc.* **1973**, *95*, 584. (b) Kollmar, H.; Smith, H. O.; Schleyer, P. v. R. *Ibid.* **1973**, *95*, 5834. (c) Dewar, M. J. S.; Haddun, R. C. *Ibid.* **1973**, *95*, 5836. (d) Hehre, W. J.; Schleyer, P. v. R. *Ibid.* **1973**, *95*, 5837. (e) Bauld, N. L.; Welsher, T. L.; Cessac, J.; Holloway, R. L. *Ibid.* **1978**, *100*, 6920. (f) Borden, W. T.; Davidson, E. R. *Ibid.* **1979**, *101*, 3771. (g) Olah, G. A.; Prakash, G. R. S.; Liang, G.; Westerman, P. W.; Kunde, K.; Chandrasekhar, J.; Schleyer, P. v. R. *Ibid.* **1980**, *102*, 4485.
(5) Saunders, M.; Berger, R.; Jaffe, A.; McBride, J. M.; O'Neill, J.; Breslow, R.; Hoffman, J. M., Jr.; Perchonock, C.; Wasserman, E.; Hutton, R. S.; Kuck, V. J. *J. Am. Chem. Soc.* **1973**, *95*, 3017.
(6) Breslow, R.; Chang, H. W.; Hill, R.; Wasserman, E. *J. Am. Chem. Soc.* **1967**, *89*, 1112.

0022-3263/82/1947-0315$01.25/0