5.74-5.92 (m, 1 H), 5.84 (d, J = 7.5 Hz, 1 H), 7.17-7.57 (m, 2 H), 7.79-8.07 (m, 2 H).

3-[1-(*m*-Chlorobenzoxy)-2-hydroxyhexyl]-4,6-dimethyl-2-pyrone (5e): white solid (32% (procedure A) and 26% (procedure B)). IR (KBr, cm^{-1}): 3520, 1716, 1688, 1641, 1552, 1285, 1260, 1249, 1139, 1075. ^1H NMR ($CDCl_3$): δ 0.70-1.06 (m, 3 H), 1.11-1.87 (m, 6 H), 2.19 (d, J = 0.7 Hz, 3 H), 2.36 (s, 3 H), 2.82 (br s, 1 H), 4.32-4.60 (m, 1 H), 5.85 (s, 1 H), 5.87 (d, J = 7.0 Hz, 1 H), 7.18-7.56 (m, 2 H), 7.80-8.02 (m, 2 H). Mass: m/z 380, 378 (M^+), 294, 292, 222, 153 (base peak). HRMS: m/z 380.1221 (calcd for $C_{20}H_{23}{}^{37}ClO_5$ 380.1205), 378.1232 (calcd for $C_{20}H_{23}{}^{35}ClO_5$ 378.1233).

3-[1,2-Bis(hydroxyhexyl)]-4,6-dimethyl-2-pyrone (6e): pale yellow viscous oil (35% (procedure A)). IR (neat, cm^{-1}): 3430, 1690, 1645, 1566. ^1H NMR ($CDCl_3$): δ 0.69-1.00 (m, 3 H), 1.00-1.78 (m, 6 H), 2.18 (s, 3 H), 2.24 (d, J = 0.7 Hz, 3 H), 3.70-3.98 (m, 1 H), 4.21-4.53 (m, 1 H), 5.92 (br s, 1 H). HRMS: m/z 223.1337 (calcd for $C_{13}H_{19}O_3$, M^+ - OH, 223.1334), 222.1252 (calcd for $C_{13}H_{18}O_3$, M^+ - H_2O, 222.1255).

Acylation of 5d with Acetic Anhydride and 4-(*N*,*N*-Dimethylamino)pyridine (DMAP) in Triethylamine. To a mixture of **5d** (303 mg, 0.9 mmol), DMAP (33 mg, 0.27 mmol) and triethylamine (0.2 mL, ca. 2.0 mmol) was added dropwise 0.14 mL (1.5 mmol) of acetic anhydride at room temperature. The reaction mixture was stirred for 30 min and diluted with 20 mL of ether. The resulting mixture was poured into 30 mL of 1 N HCl, and the organic layer was separated. After the aqueous layer was extracted with ether (2 × 10 mL), the combined organic layers were washed with 5% $NaHCO_3$ and saturated NaCl and then dried over $MgSO_4$. The removal of the solvent gave a crude product. Purification by TLC (*n*-hexane/ethyl acetate = 6/4) afforded 187 mg (55%) of **7d**. **7d**: yellow oil. IR (KBr, cm^{-1}): 1770, 1723, 1690 (sh), 1641, 1573, 1374, 1284, 1251, 1242, 1234, 1124, 1069. ^1H NMR ($CDCl_3$): δ 1.25 (d, J = 5.4 Hz, 3 H), 1.99 (s, 3 H), 2.20 (d, J = 0.9 Hz, 3 H), 2.38 (s, 3 H), 5.76-5.89 (m, 1 H), 5.85 (dq, J = 8.4, 5.4 Hz, 1 H), 6.10 (d, J = 8.4 Hz, 1 H), 7.17-7.57 (m, 2 H), 7.77-7.97 (m, 2 H). Mass: m/z 380, 378 (M^+), 139 (base peak). HRMS: m/z 380.0801 (calcd for $C_{19}H_{19}{}^{37}ClO_6$ 380.0839), 378.0870 (calcd for $C_{19}H_{19}{}^{35}ClO_6$ 378.0839).

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Registry No. *trans*-**1a**, 114144-01-3; *cis*-**1a**, 114144-05-7; *trans*-**1b**, 119274-33-8; *cis*-**1b**, 119274-34-9; *trans*-**1c**, 119274-35-0; *cis*-**1c**, 119274-36-1; *trans*-(*E*)-**1d**, 119363-81-4; *trans*-(*Z*)-**1d**, 119363-82-5; *cis*-(*E*)-**1d**, 119363-83-6; *cis*-(*Z*)-**1d**, 119363-84-7; *trans*-(*E*)-**1e**, 119274-37-2; *trans*-(*Z*)-**1e**, 119274-38-3; *cis*-(*E*)-**1e**, 119274-39-4; *cis*-(*Z*)-**1e**, 119296-10-5; *trans*-**1f**, 119274-40-7; *cis*-**1f**, 119274-41-8; *trans*-**1g**, 119274-42-9; *cis*-**1g**, 114144-06-8; **2a**, 119274-43-0; **2b**, 119274-44-1; **2c**, 119274-45-2; *E*-**2d**, 119274-46-3; *Z*-**2d**, 119274-47-4; *E*-**2e**, 119274-48-5; *Z*-**2e**, 119274-49-6; **2f**, 119274-50-9; **2g**, 119274-51-0; **3a**, 119274-53-2; *Z*-**3e**, 119274-55-4; *E*-**3e**, 119274-57-6; *cis*-**4d**, 119274-58-7; *trans*-**4d**, 119274-59-8; *trans*-**4e**, 119274-60-1; *cis*-**4e**, 119274-61-2; **5d**, 119274-62-3; **5e**, 119274-63-4; **6e**, 119274-64-5; **7d**, 119274-65-6; $AgSbF_6$, 26042-64-8; $AgBF_4$, 14104-20-2.

A Convenient Synthesis of Vicinal Diamines

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Various 3-substituted-1,2-diaminopropane compounds in which the amino groups are protected as bis(carbamates) or bis(sulfonamides) were prepared from the corresponding N,N'-bis-protected 2-(aminomethyl)aziridine derivatives by nucleophilic opening of the aziridine ring. The aziridine derivatives are ultimately derived from readily available 2-hydroxy-1,3-diaminopropane. A variety of nucleophiles can be added to incorporate various functionality (CN, O_2CCH_3, OH, Cl, CH_3, CH_2CO_2H) in the 3-position of the resulting 1,2-diaminopropane derivatives.

The vicinal diamino group plays an important role in medicinal chemistry, particularly in metal chelation.[1,2] In particular, vicinal diamines are key intermediates in the synthesis of bis thioacetamido (N_2S_2) chelating agents for ^{99m}Tc and $^{186}Re/^{188}Re$. The ^{99m}Tc N_2S_2 complexes have been of interest as renal tubular function imaging agents[1] and more recently have been applied as bifunctional chelating agents for labeling monoclonal antibody fragments for tumor imaging.[3] Rhenium radioisotopes, ^{186}Re and ^{188}Re, have appropriate physical properties for β emitter radiotherapy, and N_2S_2 ligands have demonstrated bifunctional chelating ability for antibodies for radioimmunotherapy.[4] The methods for preparing vicinal diamines are unfortunately rather limited, particularly with respect to including other functionalized groups on the molecule. Olefins react with azide anion oxidatively to form vicinal diazides.[5] The reduction of diazides to diamines is prone to alternative reactions and requires careful selection of reductants. Another drawback to the use of azides is their possible explosiveness. Olefinic hy-

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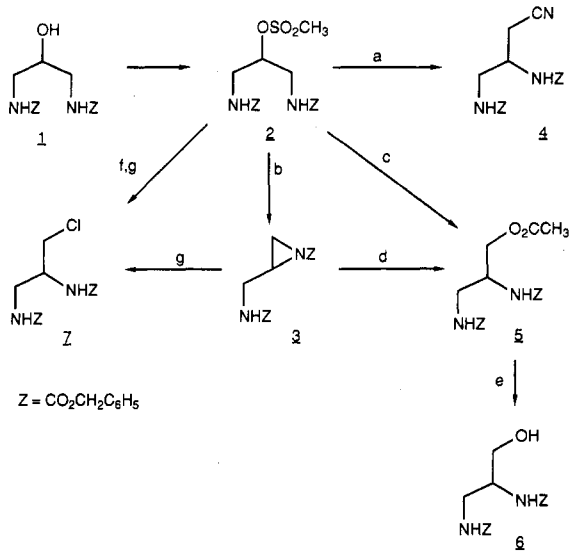
0022-3263/89/1954-1940$01.50/0

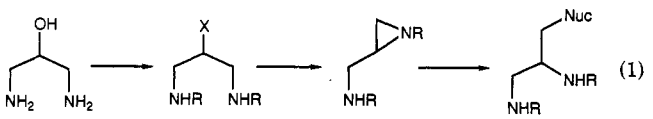
Scheme I[a]



[a](a) KCN, 18-crown-6, CH_3CN, reflux (40%); (b) NaH/DMF (60%); (c) (1) K-t-BuO/THF, (2) CH_3CO_2H, reflux (22%); (d) CH_3CO_2H, reflux (60%); (e) K_2CO_3/MeOH/H_2O (61%); (f) NaH/DMF; (g) 5% HCl solution.

drocarbons also react with cyclopentadienylnitrosylcobalt dimer and nitrous oxide to give adducts that can be reduced to vicinal diamines with lithium aluminum hydride.[5c] Vicinal diazides can also be prepared from vicinal dihalides[6] or stereospecifically from an epoxide via a hydroxy azide.[6a] Alternatively, iodoisocyanation of an olefin followed by hydrolysis results in the formation of an aziridine, which can be opened with ammonia to give a vicinal diamine stereospecifically.[6a] Cycloaddition of chlorosulfonyl isocyanate to olefins followed by a Curtius rearrangement and hydrolysis of the resulting cyclic urea gives vicinal diamines.[7] Vicinal diamines can also be prepared from olefins and cyanamide/NBS,[8] reductive amination of α-amino ketones,[7] Michael addition of urethanes of dehydroalanine derivatives,[9] reduction of α-amino nitriles,[2a] and reduction of α-amino amides.[2b] Vicinal diamines have also been prepared from dienes via a Diels–Alder adduct of sulfur dioxide bis(imides).[10]

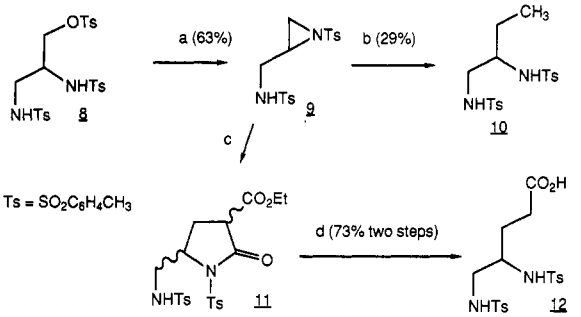
We have developed a new method for preparing vicinal diamines as their carbamoyl or sulfonyl derivatives using readily available and relatively inexpensive 1,3-diamino-2-propanol as starting material (see eq 1). The amines



X = leaving group
R = carboalkoxy or sulfonyl
Nuc = nucleophile

are converted to carbamates or sulfonamides, and the hydroxyl is converted to a leaving group. The most convenient leaving group is a sulfonate ester. Treatment with base results in ring closure to provide a 2-(aminomethyl)aziridine derivative that can be opened regiospecifically with a variety of nucleophiles. This new method allows for incorporation of a variety of functional groups as appendages on the 3-position of the resulting 1,2-diaminopropane derivative.

Scheme II[a]



[a](a) NaOMe, MeOH; (b) CH_3MgBr, THF, reflux; (c) $CH_2(CO_2Et)_2$, NaOEt, EtOH, reflux; (d) 6 N HCl, reflux.

Readily available 1,3-diamino-2-propanol was converted to the bis(carbobenzyloxy) derivative 1 (Scheme I). Subsequent conversion of 1 to 2 was accomplished by reaction with methanesulfonyl chloride. Deprotonation of 2 resulted in the formation of bis(carbobenzyloxy)-2-(aminomethyl)aziridine (3), which was found to undergo typical nucleophilic ring-opening reactions.[11] For instance, treatment of compound 3 with refluxing acetic acid produced the acetoxy derivative 5, which could be hydrolyzed to the 2,3-diamino-1-propanol derivatives 6. The preparation of 5 can be accomplished directly from 2 by deprotonation to produce the aziridine, addition of acetic acid, and heating. The chloride 7 was also prepared from 2 either with or without isolation of compound 3. Reaction of cyanide with 2 by refluxing in acetonitrile in the presence of a crown ether (18-crown-6) provided the nitrile 4. Successful alkylation of cyanide led us to attempt other carbon–carbon bond-forming ring-opening reactions.

Ring-opening alkylation of simple alkylaziridines with organocopper reagents and organolithium reagents[12a] and organolithium reagents[12b] are known processes. We found that carbon nucleophiles such as Grignard reagents or sodiomalonates resulted in loss of the carbamate protecting groups, so we were not able to isolate the desired carbon adducts. The sulfonamide derivative 9, however, was more resistant to nucleophilic displacement. Compound 9 was prepared by tosylation of 1,3-diaminopropanol with *p*-toluenesulfonyl chloride in pyridine to give compound 8, which, on treatment with methoxide, gave the aziridine 9. Compound 9 could be converted to compound 10 by being refluxed with methylmagnesium bromide in THF as shown in Scheme II. The sodium salt of diethyl malonate can also be used to open up the aziridine ring, giving rise to compound 11 as a mixture of diastereoisomers.[13] The crude mixture was hydrolyzed to the bis(tosylamide) of 4,5-diaminopentanoic acid (12) by being refluxed in 6 N HCl.

A facile method of preparing 1,2-diaminopropane derivatives that allows for incorporation of heteroatom sub-

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(13) Intermediate 11 was purified by silica gel chromatography (40% EtOAc/hexanes) to give an oil. Trituration with Et_2O gave a white solid, which was collected by filtration. Analysis by ^1H NMR confirms that a mixture of diastereoisomers is present: ^1H NMR ($CDCl_3$) 1.24 (t, 2.1 H), 1.26 (t, 0.9 H), 2.47 (s, 3 H), 2.48 (s, 3 H), 2.45–2.62 (m, 2 H), 3.36–3.43 (m, 2 H), 3.51 (dd, J = 7 Hz and 12 Hz, 0.3 H) 3.85 (dd, J = 8 Hz and 10 Hz 0.7 H), 4.12–4.29 (m, 2 H), 4.40–4.52 (m, 1 H), 5.23 (t, J = 8 Hz, 0.7 H), 5.41 (t, J = 7 Hz, 0.3 H), 7.29–7.41 (m, 4 H), 7.79–7.96 (m, 4 H).

stituents or carbon–carbon bonds at the 3-position has been demonstrated. Heteroatomic nucleophiles including carboxylate and halogen reacted with (aminomethyl)-aziridine derivative **3** to provide 1,2-diaminopropane derivatives with the heteroatom substitutent in the 3-position. We have been able to form carbon–carbon bonds by using cyanide, Grignard reagents, or sodiomalonates to open up the aziridine ring. We are exploring the use of 2-(aminomethyl)aziridine derivatives to prepare a variety of otherwise difficult to prepare chelating agents based on vicinal diamines for use in the diagnosis and therapy of cancer.

Experimental Section

Proton magnetic resonance (^{1}H NMR) spectra were recorded on a Varian Model Gemini 200 (200MHz) spectrometer or a Varian Model EM-360 (60 MHz) spectrometer. Chemical shifts are reported in parts per million (δ) downfield from tetramethylsilane (TMS). Carbon magnetic resonance (^{13}C NMR) spectra were recorded on a Varian Gemini 200 (50 MHz) spectrometer. Infrared spectra were recorded on a Perkin-Elmer Model 1310 spectrophotometer. Mass spectra were recorded on a VG7070H double focusing mass spectrometer with a VG2035 data system. Melting points are reported uncorrected in degrees Centigrade. Elemental analyses were performed by Desert Analytics Organic Microanalysis, Tucson, AZ. Chromatographic purifications on silica gel were performed on silica gel, Merck, grade 60, 230–400 mesh, 60A (Aldrich Chemical Company).

***N,N'*-Bis(carbobenzyloxy)-1,3-diamino-2-hydroxypropane (1).** To a solution of 18 g (200 mmol) of 1,3-diamino-2-hydroxypropane in 50 mL of 1 N NaOH at 0 °C was added 62.8 mL (75 g, 440 mmol) of benzyl chloroformate. The mixture was stirred vigorously for 18 h, and the resulting solid material was collected by vacuum filtration. Crystallization from EtOAc/hexanes yielded 17.7 g (25%) of needles: mp 122–123 °C; ^{1}H NMR ($CDCl_3$) 3.27 (dd, 4 H), 3.78 (m, 1 H), 5.12 (s, 4 H), 5.49 (m, 2 H), 7.37 (m, 10 H); IR (KBr) 3325, 1685 cm^{-1}. Anal. Calcd for $C_{19}H_{22}N_2O_5$: C, 63.67; H, 6.19; N, 7.82. Found: C, 63.60; H, 6.17; N, 7.84.

***N,N'*-Bis(carbobenzyloxy)-1,3-diaminopropan-2-ol Methanesulfonate (2).** To a suspension of 21.0 g (58.5 mmol) of **1** and 12.2 mL (8.87 g, 87.7 mmol) of Et_3N in 292 mL of CH_2Cl_2 at 0 °C was added 4.98 mL (7.37 g, 64.4 mmol) of methanesulfonyl chloride over a 6-min period. The mixture became a clear solution by the time addition was complete and was stirred for 1 h at 0 °C. The mixture was washed in succession with chilled 150-mL portions of 5% HCl solution, H_2O, 10% Na_2CO_3 solution, and saturated NaCl solution, dried ($MgSO_4$), filtered, and concentrated under vacuum to give 16.9 g (66%) of white needles: mp 94–95.5 °C; ^{1}H NMR ($CDCl_3$) 2.97 (s, 3 H), 3.48 (dd, 4 H), 4.73 (dd, 1 H), 5.13 (s, 4 H), 5.49 (m, 2 H), 7.22 (s, 10 H); IR (KBr) 3300, 1690, 1540 cm^{-1}. Anal. Calcd for $C_{20}H_{24}N_2O_7S$: C, 55.03; H, 5.54; N, 6.42; S, 7.35. Found: C, 55.35; H, 5.59; N, 6.49; S, 7.26.

***N,N'*-Bis(carbobenzyloxy)-2-(aminomethyl)aziridine (3).** To 30 mL of anhydrous DMF under an N_2 atmosphere was added 600 mg of NaH (60% oil dispersion) (15 mmol). The mixture was cooled to 0 °C, and a solution of 6.54 g (15 mmol) of **2** in 30 mL of anhydrous DMF was added over 5 min. The mixture was stirred for 30 min at 0 °C, poured into 200 mL of cold water, and shaken in a separatory funnel with 200 mL of EtOAc. The EtOAc layer was washed with a saturated NaCl solution, dried ($MgSO_4$), filtered, and concentrated under vacuum to give 6.0 g of a viscous oil. Purification by medium pressure chromatography on silica gel (40% EtOAc/hexanes) yielded 3.04 g (60%) of **3** as an oil: ^{1}H NMR ($CDCl_3$) 2.10 (d, J = 3 Hz, 1 H), 2.36 (d, J = 6 Hz, 1 H), 2.65 (m, 1 H), 3.14 (m, 1 H), 3.62 (m, 1 H), 5.09 (s, 2 H), 7.33 (s, 10 H); ^{13}C NMR (75 MHz, $CDCl_3$) 30.2, 37.4, 42.6, 67.5, 68.9, 128.6, 128.7, 129.0, 129.1, 136.1, 136.8, 156.8, 163.2; mass spectrum (CI), m/z (intensity) 341 (6), 91 (100); HRMS (CI), calcd for $C_{19}H_{21}N_2O_4$ 341.1505, found 341.1503.

3,4-[Bis(carbobenzyloxy)amino]butyronitrile (4). A mixture of 6.55 g (15 mmol) of **2**, 1.08 g (16.5 mmol) of KCN, 0.40 g (1.5 mmol) of 18-crown-6, and 75 mL of anhydrous acetonitrile (stored over 3-Å molecular sieves) was refluxed in a nitrogen atmosphere for 19 h. When cool, the mixture was partitioned between 100 mL of 10% $NaHCO_3$ solution and 200 mL of CH_2Cl_2. The CH_2Cl_2 layer was washed successively with 100-mL portions of 5% HCl solution, H_2O, and brine. The CH_2Cl_2 phase was dried ($MgSO_4$), filtered, and concentrated to give 5.47 g of brown oil. Two recrystallizations from $CHCl_3$/hexane yielded 2.68 g (40%) of **4** as a white solid: mp 111–112 °C; ^{1}H NMR ($CDCl_3$) 2.65 (d, J = 6 Hz, 2 H), 3.42 (two overlapping doublets, 2 H), 3.97 (m, 1 H), 5.13 (s, 4 H), 5.35 (br s, 1 H), 5.84 (br s, 1 H), 7.35 (s, 10 H); mass spectrum (CI), m/z (intensity) 368 (24), 325 (93), 181 (88), 107 (100). Anal. Calcd for $C_{20}H_{21}N_3O_4$: C, 65.38; H, 5.76; N, 11.44. Found: C, 65.42; H, 5.80; N, 11.46.

***O*-Acetyl-*N,N'*-bis(carbobenzyloxy)-2,3-diaminopropan-1-ol (5).** To a solution of 4.41 g (10 mmol) of **2** in 50 mL of anhydrous THF at 0 °C under an N_2 atmosphere was added 1.74 g (15 mmol) of potassium *tert*-butoxide. The mixture was stirred for 20 min at 0 °C, and 50 mL of acetic acid was added. The flask was fitted with a reflux condenser, and the mixture was refluxed for 20 min. The solvents were removed via rotary evaporator, and the residue was partitioned between 100 mL of H_2O and 100 mL of EtOAc. The EtOAc layer was dried ($MgSO_4$), filtered, and concentrated to yield 3.3 g of an oily solid. Purification by silica gel chromatography (50% EtOAc/hexanes) followed by crystallization from hexanes/EtOAc yielded 892 mg (22%) of a white solid: mp 125–126 °C; ^{1}H NMR ($CDCl_3$) 2.01 (s, 3 H), 3.15–3.59 (m, 3 H), 3.80–4.15 (m, 2 H), 5.14 (s, 4 H), 5.60–5.15 (br m, 2 H), 7.38 (s, 10 H); HRMS (CI), calcd for $C_{21}H_{24}N_2O_6$ 401.1712, found 401.1688.

***N,N'*-Bis(carbobenzyloxy)-2,3-diaminopropan-1-ol (6): Hydrolysis of 5.** To a solution of 212 mg (1.53 mmol) of K_2CO_3 in 0.5 mL of H_2O and 6 mL of MeOH was added 212 mg (0.53 mmol) of **5**. The mixture was stirred for 1 h at 20 °C and partitioned between 20 mL of H_2O and 2 × 10 mL of EtOAc. The EtOAc layers were combined, dried ($MgSO_4$), filtered, and concentrated to yield a viscous oil. Trituration with hexane/Et_2O gave a white powder, which was collected by vacuum filtration to yield 116 mg (61% of **6**: mp 103–105 °C; ^{1}H NMR ($CDCl_3$) 3.10–3.96 (m, 6 H), 5.10 (s, 4 H), 5.55 (m, 2 H), 7.35 (s, 10 H); mass spectrum (CI), m/z (intensity) 359 (19), 251 (100). Anal. Calcd for $C_{19}H_{22}N_2O_5$: C, 63.67; H, 6.19; N, 7.82. Found: C, 63.61; H, 6.36; N, 7.92.

***N,N'*-Bis(carbobenzyloxy)-1,2-diamino-3-chloropropane (7).** To a suspension of 200 mg of a 60% oil dispersion of NaH (5 mmol) in 25 mL of DMF at 0 °C was added dropwise a solution of 2.18 g (5 mmol) of **2** in 25 mL of DMF. The mixture was stirred for 1 h, and 40 mL of 5% HCl solution was added. The mixture was extracted with 50 mL of Et_2O. The Et_2O layer was washed with saturated NaCl solution, dried ($MgSO_4$), filtered, and concentrated to give 1.33 g (79%) of a white solid, which was recrystallized from EtOH/H_2O: mp 118–119 °C; ^{1}H NMR ($CDCl_3$) 3.35 (m, 2 H), 3.57 (m, 2 H), 4.00 (m, 1 H), 5.05 (s, 4 H), 5.38 (m, 1 H), 5.68 (m, 1 H), 7.30 (s, 10 H); ^{13}C NMR ($CDCl_3$) 42.9, 45.3, 53.0, 65.8, 67.6, 67.7, 127.5, 128.0, 128.6, 129.0, 136.6, 156.6, 157.7; IR (KBr) 1680, 1535, 1260, 735, 690 cm^{-1}; mass spectrum (CI), m/z (intensity) 377 (45), 333 (99), 181 (100); HRMS (CI), calcd for $C_{19}H_{22}ClN_2O_4$ 377.1263, found 377.1269.

***N,N',O*-Tris(*p*-tolylsulfonyl)-1,3-diamino-2-hydroxypropane (8).** To a solution of 9.0 g (100 mmol) of 1,3-diamino-2-hydroxypropane in 200 mL of pridine at 0 °C was added in portions 62.9 g (330 mmol) of *p*-toluenesulfonyl chloride. The mixture was stirred at room temperature overnight and poured onto 200 g of crushed ice. After 1–2 h the mixture formed a granular pink solid, which was collected by filtration to give 48.4 (87%) of crude **1c**, which was used as is. An analytical sample was prepared by silica gel chromatography (50% EtOAc/hexanes) and concentrated under vacuum to give a white foam: ^{1}H NMR ($CDCl_3$) 2.49 (s, 9 H), 3.20 (dd, 4 H), 4.62 (t, 1 H), 5.43 (t, 2 H), 7.11–8.00 (m, 12 H). The foam could not be crystallized, was difficult to purify further, and gave no parent ion by CI mass spectroscopy. Since subsequent compounds gave good analytical data, we are confident of the structure of **8**.

***N,N'*-Bis(*p*-tolylsulfonyl)-2-(aminoethyl)aziridine (9).** To a solution of 5.52 g (10 mmol) of **8** in 50 mL of MeOH at 0 °C was added dropwise over 2 min 20 mL of 1 N NaOMe. The mixture was stirred for 1 h at 0 °C and partitioned between 125 mL of EtOAc and 2 × 125 mL of saturated NaCl. The EtOAc

layer was dried ($MgSO_4$), filtered, and concentrated to yield an oil. The oil was purified by silica gel chromatography (40% EtOAc/hexanes), concentrated to an oil, and triturated with Et_2O to give 2.42 g (63%) of **9** as a white solid: mp 118–119 °C; ^1H NMR ($CDCl_3$) 2.22 (d, J = 4 Hz, 1 H), 2.44 (s, 3 H), 2.49 (s, 3 H), 2.55 (d, J = 7 Hz, 1 H), 2.91 (m, 1 H), 3.06 (m, 1 H), 3.18 (m, 1 H), 4.98 (t, 1 H), 7.31 (d, J = 8 Hz, 2 H), 7.36 (m, J = 8 Hz, 2 H), 7.71 (d, J = 8 Hz, 2 H), 7.79 (d, J = 8 Hz, 2 H); ^{13}C NMR ($CDCl_3$) 22.3 (q), 32.5 (t), 38.6 (d), 43.8 (t), 127.5 (d), 128.5 (d), 130.3 (d), 134.5 (s), 137.1 (s), 144.1 (s), 145.5 (s); mass spectrum (CI), m/z (intensity) 381 (100), 155 (95). Anal. Calcd for $C_{17}H_{20}N_2O_4S_2$: C, 53.66; H, 5.30; N, 7.36; S, 16.85. Found: C, 53.78; H, 5.39; N, 7.41, S, 16.73.

***N,N'*-Bis(*p*-tolylsulfonyl)-1,2-diaminobutane (10). Addition of Methylmagnesium Bromide to 9.** To a solution of 380 mg (1 mmol) of **9** in 5 mL of anhydrous THF under an N_2 atmosphere was added 1 mL (3 mmol) of 3 M MeMgBr solution in diethyl ether, and the mixture was refluxed for 15 h. When cool, the mixture was partitioned between 20 mL of pH 7 buffer and 2 × 20 mL of EtOAc. The combined EtOAc layers were dried ($MgSO_4$), filtered, and concentrated to give 399 mg of an oil, which was purified by chromatography on silica gel (30% EtOAc/hexanes) to give an oil, which solidified on trituration with Et_2O/hexanes. The solid was collected by vacuum filtration to give 116 mg (29%) of **10**: ^1H NMR ($CDCl_3$) 0.68 (t, 3 H), 1.30 (m, 2 H), 2.35 (s, 6 H), 2.96 (m, 2 H), 3.44 (m, 1 H), 5.10 (m, 2 H), 7.09–7.45 (m, 4 H), 7.49–7.96 (m, 4 H); mass spectrum (CI), m/z (intensity) 397 (100); HRMS (CI), calcd for $C_{18}H_{24}N_2O_4S_2$ 397.1268, found 397.1239.

***N,N'*-Bis(*p*-tolylsulfonyl)-4,5-diaminopentanoic Acid (12).** To 380 mg (1 mmol) of **9** and 454 μL of diethyl malonate was added 10 mL of 0.3 M NaOEt made by treating 100 mL of EtOH with 690 mg (30 mmol) of Na. The resulting solution was refluxed for 1.25 h and partitioned between 50 mL of H_2O and 50 mL of EtOAc. The EtOAc layer was washed with saturated NaCl, dried ($MgSO_4$), filtered, and concentrated to give 450 mg of viscous oil. To the oil was added 50 mL of 6 N HCl, and the mixture was refluxed for 1.5 h. When cool, the mixture was extracted with 50 mL of EtOAc. The EtOAc layer was washed with saturated NaCl, dried ($MgSO_4$), filtered, and concentrated to give an oil, which was crystallized from EtOAc/hexanes to give 208 mg (73%) of a white solid: mp 165–166 °C; ^1H NMR (CD_3OD) 2.08 (m, 2 H), 2.70 (m, 2 H), 3.26 (m, 2 H) 3.65–4.25 (br m, 1 H), 7.34 (d, J = 8 Hz, 4 H), 7.60 (d, J = 8 Hz, 2 H), 7.70 (d, J = 8 Hz, 2 H); IR (KBr) 3660–2770, 1710, 1320, 1160, cm^{-1}; mass spectrum (CI), m/z (intensity) 423 (72), 269 (100). Anal. Calcd for $C_{19}H_{24}N_2O_6S_2$: C, 51.70; H, 5.49; N, 6.36; S, 14.56. Found: C, 52.10; H, 5.62; N, 6.30; S, 14.33.

Registry No. **1**, 119244-91-6; **2**, 119244-92-7; **3**, 119244-93-8; **4**, 105655-80-9; **5**, 119244-94-9; **6**, 54798-70-8; **7**, 119244-95-0; **8**, 119244-96-1; **9**, 119244-97-2; **10**, 119244-99-4; *trans*-**11**, 119244-99-4; *cis*-**11**, 119245-01-1; **12**, 119245-00-0; 1,3-diamino-2-hydroxypropane, 616-29-5; benzyl chloroformate, 501-53-1.

Electrochemical Study of the Nonaqueous Oxidation of Dipyrrolic Compounds

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With use of cyclic voltammetry, electrochemical oxidation potentials vs Ag/AgCl in acetonitrile of 26 pyrromethanes, 10 pyrromethenes, and 2 pyrroketones are measured. Compounds of these types are valuable intermediates in the organic synthesis of porphyrins. Analysis of the measured potentials shows that substituent partial potentials previously established for monopyrroles (Tabba and Smith, *J. Org. Chem.* **1984**, *49*, 1870) can usually be used to accurately predict the experimental data, except under circumstances where pyrromethanes possess a terminal α-methyl group. An ECE mechanism is proposed for the electrochemical oxidation of pyrromethanes **1**, which are shown to afford pyrromethene salts **2** by way of a two-electron oxidation at a potential approximating the corresponding monopyrrole calculated value. An additional wave at higher potential probably corresponds to oxidation of the pyrromethene **2**, and this potential is pH sensitive. A pyrromethane (**42**) bearing a *gem*-dimethyl function at the interpyrrole carbon and acetonepyrrole (**43**) fail to afford pyrromethene upon oxidation, and their insulated dipyrrole or polypyrrole systems behave as simple monopyrroles.

Introduction

In a recent paper[4] we reported the anodic oxidation potentials of 117 pyrroles comprising a diverse variety of substitution patterns and derived substituent partial potentials for most pyrrolic substituents found in intermediates for porphyrin synthesis. Other authors have shown that oxidation of pyrroles in the presence of various nucleophiles affords regioselectively substituted products.[5] Electrochemical oxidations of open-chain tetrapyrroles[6] and porphyrins[7] have also been reported. More recently, Falk[8] reported electrochemical oxidations of a pyrromethene and several pyrromethenones. So far as we are aware, no in depth study of the anodic oxidation, or cyclic voltammetry, of the common dipyrroles, pyrromethanes **1**, pyrromethenes **2**, or pyrroketones **3**, has been reported. In this paper we describe a detailed investigation of the cyclic voltammetry of a large variety of dipyrroles that are in-

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