reasonably comparable to structures usually written for amidinium ions.[6] The resonance forms **3a–c** would appear, if anything, to enhance the acidity of **1b** by charge delocalization. However, there is a possibility that failure of **1** to dissolve in alkali, when other sulfa derivatives are soluble, could be ascribed to a very much lower water solubility of **1**. However, this cannot be the case, because, in fact, **1** is substantially more soluble in neutral water than the other sulfa derivatives.[2]

The only reasonable explanation for low basicity and acidity of **1b** vs. what might otherwise be expected seems to be through some special stabilizing characteristic of **1b** which is not shared to the same extent by **2** or **3** (or by the corresponding conjugate bases). One such possibility is delocalization of the lone pair on nitrogen to sulfur, as expressed by **4**. The fact that the two $-NH_2$ groups of the guanidine have
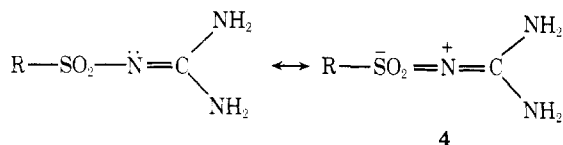
no appreciable chemical-shift difference is in accord with an important contribution of **4**.[8]

Registry No.—**1b**, 61116-95-8.

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(1) Supported by the Public Health Service, Research Grant 11072 from the Division of General Medical Sciences, and by the National Science Foundation.
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"Abnormal" Displacement in the Reaction of 2-(N-Methylpyrrolyl)methyltrimethylammonium Salts with Sodium Cyanide

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It has been known for some time that the reaction of 2-(chloromethyl)furan (**1**) with metal cyanides can proceed in two directions, "normal" displacement to afford **2**, as well as "abnormal" substitution to afford **3**,[1] whereas the reaction of
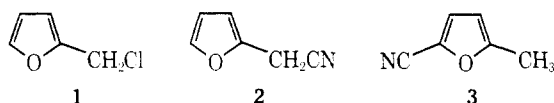
benzyl halides with cyanide occurs with direct substitution. Although much attention has been focused on this process in the chemistry of furans,[2] no intensive studies have been performed on cyanide displacement with corresponding pyrrole derivatives. We wish to report on the reaction of 2-pyrrolylmethylammonium salts (**4**) with sodium cyanide. Under a variety of conditions, this operation produces not only N-methylpyrrole-2-acetonitrile (**5**), as reported earlier by others,[3]

4a, X = I   **5**
  b, X = OSO_2OCH_3
  c, X = OSO_2-4-$CH_3C_6H_4$
  d, X = Cl
  e, X = OSO_2CF_3

6   **7**
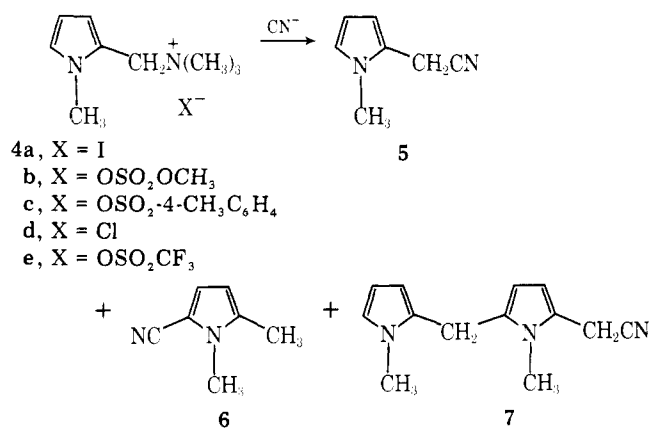
but also significant amounts of heretofore unrecognized, "abnormal" nitrile (**6**). Furthermore, thorough analysis of the reaction mixtures revealed minor dipyrrolylmethane by-products, **7** and **8**, signaling the participation of an ion-pair process in the cyanolysis.

When quaternary ammonium salts[4] **4** were heated in solution with sodium (or potassium) cyanide, trimethylamine was evolved. Temperatures of 80–95 °C afforded a reasonable reaction rate, with total reaction times of 1.5–3 h. GLC analysis of a crude organic product from the reaction of **4d** (xylene/water) revealed that three volatile substances were generated. Distillation of the product mixture provided in 78% yield a fraction composed of isomeric (mol wt 120) nitriles (GLC/MS, IR) in a ratio of ca. 9:1, assigned structures **5** and **6**, respectively (vide infra). Kugelrohr distillation of the residue furnished a yellow solid (mol wt 213) nitrile (MS, IR) in 8% yield, leaving behind some dark tar.

A mixture of the isomeric nitriles was resolved by fractional distillation to provide a sample of pure **5** (mp 28–29 °C) and a fraction highly enriched in **6**; recrystallization (CH_3OH) supplied a sample of pure **6** (mp 53–55 °C). The higher boiling nitrile was recrystallized (Et_2O) to give a pure sample of **7** (mp 88–89 °C). Full spectral data, which support these structural assignments, are provided in the Experimental Section.

Five salts differing in their counterion were investigated under various circumstances. In every case, a mixture of isomeric products **5** and **6** was formed. Compound **7** was generally a minor product (1–8%), although slightly higher yields of **7** (10–15%) were obtained when the reaction was conducted in aqueous solution under comparatively dilute conditions. Results of some representative experiments are presented in Table I. The data indicate that the amount of "abnormal" substitution, ranging from 10 to 40%, is greatly dependent on the reaction medium (cf., e.g., entries 2, 7, 11, 12, 15, and 16; 4, 9, 13, and 14) and, to a lesser extent, on the counterion of substrate **4** (cf. entries 1–5; 6–10). No conditions have yet been discovered where the "abnormal" reaction mode is absent, or for that matter, reduced below a minimum level of 8–10%.[5] In contrast to the solvent dependence observed here, 2-(chloromethyl)furan (**1**) yields predominantly "abnormal" product **3** in polar, protic media and "normal" product **2** in dipolar, aprotic media.[2b]

Salt **4b** decomposed in water in less than 3 h at 90 °C (but decomposed slowly at 50 °C). Subsequent addition of sodium cyanide to the decomposed material (in situ) did not generate any **5** or **6**. Of eight volatile substances detected (GLC) in the tarry product derived from the thermal degradation experiment, the three major ones were identified (MS) as **8a–c**. This suggests the possible existence of an electrophilic intermediate such as **9**, which combines in situ with N-methylpyrrole originating from **4**, presumably via a demethylation/retro-Mannich reaction sequence.[6] Similarly, the source of dipyrrolylmethane **7** may be explained in terms of the interception

Table I. Results for the Reaction of 4 with Sodium Cyanide[a]

Entry	Compd	[CN]₀[b]	Medium	Temp, °C	% 5 and 6[c]	% 6 in 5 and 6[c]
1	4a	12.5	Xylene/water	Reflux[d]	57	16
2	4b	12.5	Xylene/water	Reflux[d]	87	12.5
3	4c	12.5	Xylene/water	Reflux[d]	69	11.5
4	4d	12.5	Xylene/water	Reflux[d]	89	10
5	4e	12.5	Xylene/water	Reflux[d]	68	23.5
6[c]	4a	6.25	Me₂SO	85, 80	91, 92	31, 34
7[c]	4b	6.25	Me₂SO	80	86, 75	35, 36
8	4c	6.25	Me₂SO	85	82	33
9[c]	4d	6.25	Me₂SO	80	86, 69	40, 40
10	4e	6.25	Me₂SO	80	80	34
11	4b	12.5	Water	80	60	13
12	4b	6.25	Water	80	49	11
13	4d	12.5	Water	80	68	12
14	4d	6.25	Water	80	52	10
15	4b	11.5	*f*	80	88	22
16	4b	satd[g]	C₂H₅OH	Reflux	70	31

[a] Reactions were carried out using a NaCN/4 ratio of 2.5 to 1. [b] Initial molar concentration of cyanide. [c] Yields of 5 and 6 were determined by GLC using an internal reference (added during workup) and detector response factors. Standard error in the analytical data is estimated to be at most ±2%. [d] Approximately 94 °C (azeotrope). [c] Results presented for two reactions (respectively). [f] Ethylene glycol/water, 8:1. [g] Reaction arranged to have initial concentration of 3.0 M, but NaCN did not appear to dissolve completely, even at boiling point of solvent.

of azafulvalenium intermediate **9** by nitrile **5**.[7] Deliberate decomposition of **4b** at 90 °C in the presence of **5** (2 molar equiv) produced **7** in 28% yield (purified).
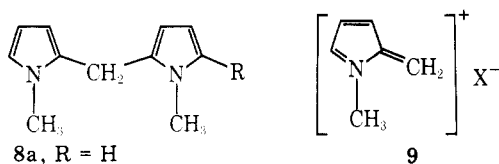
8a, R = H
  b, R = *N*-methyl-2-
    pyrrolylmethyl
  c, R = 5-(N'-methyl-
    2-pyrrolylmethyl)-
    N-methyl-2-
    pyrrolylmethyl

9

The cyanolysis of **4** may entail bimolecular (SN2/SN2'), unimolecular (SN1), or combination mechanisms. By-product **7**, together with the thermal decomposition results, suggests that this reaction may proceed, at least in part, by an SN1 process involving ion pair **9**. The fact that the counterion of **4** has an influence on the product distribution supports this view.

In conclusion, we wish to point out that this work indicates a greater generality for "abnormal" displacement in substitution reactions of five-membered-ring heteroarylmethyl compounds.

Experimental Section

Boiling points are uncorrected; melting points are corrected. ¹H NMR spectra were recorded on a Perkin-Elmer R-32 instrument at 90 MHz, and chemical shifts are reported in parts per million downfield from tetramethylsilane (internal reference). IR spectra were determined on a Perkin-Elmer 521 spectrophotometer; UV spectra were obtained on a Cary 14 instrument; mass spectra were recorded on a Hitachi Perkin-Elmer RMU-6 spectrometer at an ionizing energy of 70 eV. GLC analyses were performed on a Perkin-Elmer Model 3920 gas chromatograph, connected to a Hewlett-Packard 3352 data system, using a 6 ft × 0.125 in., 1.35% OV-17 on Chromosorb W AW/DMS column.

Quaternary Ammonium Salts. A stirred solution of newly distilled 2-dimethylaminomethyl-*N*-methylpyrrole[3a] in dry benzene, in a flask immersed in a water bath at ambient temperature, was treated with a solution of the appropriate methylating agent (1 molar equiv) in dry benzene. After addition, the reaction mixture was stirred for an additional 1 h. The solid which separated was collected by fil-

tration, rinsed with dry ether, and dried in vacuo at room temperature for 2–3 h. The salts, characterized and assayed by ¹H NMR, were >98% pure (2% limit to the analytical procedure). All of the salts were thermally unstable and decomposed slowly even at room temperature. Attempted recrystallization of **4c** and **4d** resulted in some decomposition (and darkening). The products were stored unchanged at −20 °C for over 1 year. The triflate salt **4e** appeared to be the most thermally stable of the five salts and a satisfactory elemental analysis was obtained on this material, isolated directly from the methylation reaction (mp 103–104 °C, turned pink).

General Cyanolysis. Sodium cyanide and the appropriate reaction medium were heated at the desired temperature and the ammonium salt was added. The reaction mixture was heated until the amount of product nitriles was no longer increasing. The mixture was diluted with toluene and water, an internal reference was mixed in (α-naphthol, hexadecane, or bibenzyl), and the organic layer was separated. Control experiments with pure nitriles and the internal reference served to validate the assay procedure.

Isolation of 5, 6, and 7. The organic phase from a 0.1-mol experiment with **4d** in xylene/water was concentrated to an oil. The oil was distilled [bp 65–72 °C (1.0 Torr)] to give a 78% yield of **5** and **6**, in a ratio of ca. 9:1, respectively. Separation of **5** and **6** was generally effected by fractional distillation of mixtures largely enriched in **5** using a 1.5-ft column packed with porcelain saddles. Pure **5** had bp 60–61 °C (0.005 Torr) [mp 28–29 °C; IR (neat) νmax 3105, 2950, 2250 (CN), 1490, 1410, 1312, 1290, 1196, 1086, 715 cm⁻¹; ¹H NMR (CDCl₃) δ 3.49, 3.53 (pair of s, 5 H, 1-CH₃ and CH₂CN, respectively), 6.03 (m, 2 H), 6.55 (t, 1 H, J = ca. 2 Hz, 5-H); UV (CH₃OH) λmax (ε) 217 nm (7350); MS m/e (rel abundance) 120 (100), 119 (93), 94 (93), 93 (46), 92 (36), 51 (32), 44 (86)] and a fraction highly enriched in **6** had bp 39–41 °C (0.005 Torr). A sample of pure **6**, obtained by recrystallization from methanol, had mp 53–55 °C [IR (KBr) νmax 3120, 2915, 2200 (conjugated CN), 1460, 1430, 1393, 1380, 1315, 1173, 1028, 773 cm⁻¹; ¹H NMR (CDCl₃) δ 2.23 (s, 3 H, W₁/₂ = ca. 1.5 Hz, 5-CH₃), 3.61 (sharp s, 3 H, 1-CH₃), 5.90 (broadened d, 1 H, J = ca. 4 Hz, 4-H), 6.66 (sharp d, 1 H, J = ca. 4 Hz, 3-H); UV (CH₃OH) λmax (ε) 227 (5860), 258 nm (15 400); MS m/e (rel abundance) 120 (72), 119 (83), 44 (100), 40 (83)]. Compound **7** was typically isolated from the pot residue of the initial distillation by flash distillation (Kugelrohr). A sample of pure **7**, obtained by recrystallization from dry ether, had mp 88–89 °C [IR (KBr) νmax 3105, 2895, 2250 (CN), 1490, 1455, 1415, 1312, 1290, 1199, 1019, 1006, 770, 760, 705 cm⁻¹; ¹H NMR (CDCl₃) δ 3.44, 3.49 (pair of s, 6 H, 1-CH₃ and 1'-CH₃), 3.61 (s, 2 H), 3.83 (s, 2 H), 5.78 (m, 2 H), 6.03 (m, 2 H), 6.54 (m, 1 H); UV (CH₃OH) λmax (ε) 223 nm (15 200); MS m/e (rel abundance) 213 (100), 212 (58), 173 (81), 132 (50), 94 (92), 93 (54)]. Satisfactory elemental analyses (C, H, N) were obtained for the new substances, **6** and **7**.

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(4) Prepared by methylation of 2-dimethylaminomethyl-*N*-methylpyrrole[3a] using a suitable reagent.
(5) This fact raises the question as to whether other reported reactions of N-substituted pyrrolylmethylammonium salts actually produced only the "unrearranged" (or "normal") nitrile: see ref 3a; W. Herz and R. L. Settine, *J. Org. Chem.*, **24**, 201 (1959).
(6) Carbon–carbon bond cleavages of this type are not unprecedented in pyrrole chemistry; see, e.g., W. M. Quattlebaum, Jr., and A. H. Corwin, *J. Am. Chem. Soc.*, **64**, 922 (1942).
(7) Azafulvalenium ions may be implicated in various aspects of pyrrole chemistry,[8a,8c] and two examples of isolable salts from NH pyrroles have been reported.[8b,8c]
(8) (a) E.g., R. M. Silverstein, E. E. Ryskiewicz, C. Willard, and R. C. Koehler, *J. Org. Chem.*, **20**, 668 (1955); D. Klamann, P. Weyerstahl, and H. Dujmovits, *Justus Liebigs Ann. Chem.*, **714**, 76 (1968); (b) P. E. Sonnet, *J. Heterocycl. Chem.*, **7**, 1101 (1970), and references cited therein; (c) K. Hafner and K. Pfeiffer, *Tetrahedron Lett.*, 4311 (1968).


Carbon–Carbon Reductive Cleavage during Metal–Ammonia Reaction

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The majority of metal–ammonia reactions (Birch reductions) do not involve carbon–carbon bond cleavage.[2] We have recently observed that the photodimers **1**[3] and **2**[4] are selectively cleaved to hydrocarbons **3**[5] and **4**,[6] respectively, on
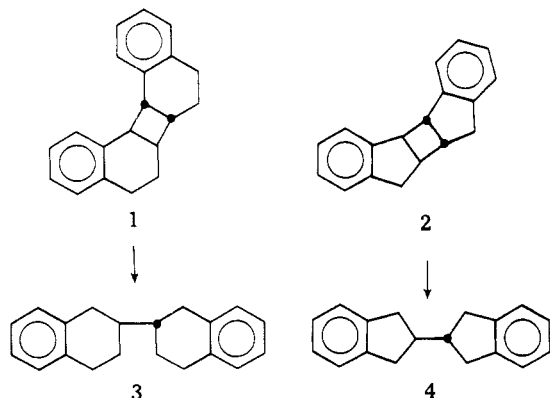
treatment with lithium or sodium in ether–ammonia. Hydrocarbons **1** and **2** react rapidly and a permanent blue color is not observed until after addition of 2 equiv of metal.

In contrast, hydrocarbons **5**[7] and **6**,[4] isomers of **1** and **2**, respectively, are totally inert to the lithium–ammonia cleavage reaction under comparable conditions. We attribute this spectacular difference in reactivity to a combination of steric strain and contiguous benzylic positions in **1** and **2**. We have

recently obtained an x-ray crystallographic analysis[3] of hydrocarbon **1**, which shows that the four-membered ring is planar and has an elongated bond (1.579 Å). Interestingly, it is this bond which is cleaved during the lithium–ammonia reduction. We have also determined that **7**[8a] is inert to Na–
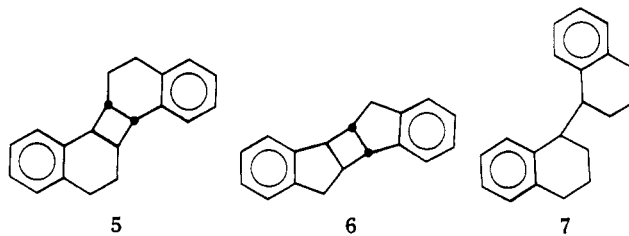

NH$_3$ reductive cleavage. Comparison of structures **1**, **5**, and **7** suggests that relief of steric strain is involved in the reductive cleavage of **1**.

We offer the rationalization shown in Scheme I as an ex-

Scheme I
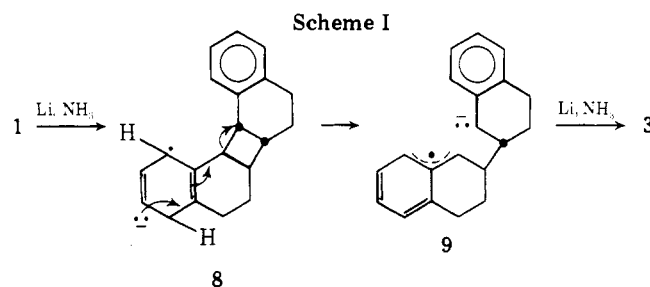
planation for the process and feel that while relief of steric strain is important, the availability of a benzylic position to stabilize the anion in structure **9** is an essential factor. Base-induced cleavage of **1** and **2** without the assistance of a reductive process is unlikely, since these hydrocarbons are stable to strong anhydrous base.[8b]

Recent reviews provide a few examples of carbon–carbon reductive cleavage.[2] The major structural features responsible for this effect are vicinal benzylic positions and/or relief of strain, as implied above. Whereas 1,2-diarylethanes appear to be stable to reduction,[9] tri- and tetraarylethanes are known to cleave.[10] If **10** is considered to be a diarylethane, it should
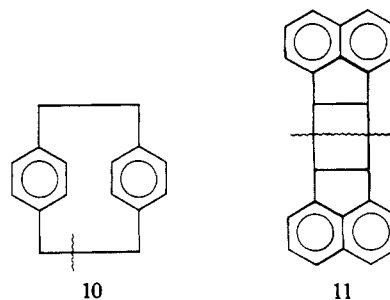
be stable. However, cleavage of the carbon–carbon bond as shown indicates that relief of steric strain must be essential.[11] Cleavage of the cyclobutane ring of **11** with sodium to the radical anion of acenaphthalene has been established by ESR studies.[12]

It is of interest that while hydrocarbon **7** is unaffected by the Li–NH$_3$ reaction, the diol **12**[13] is cleaved to tetralin in