Synthesis and Decomposition of Functionalized Diaziridinimines

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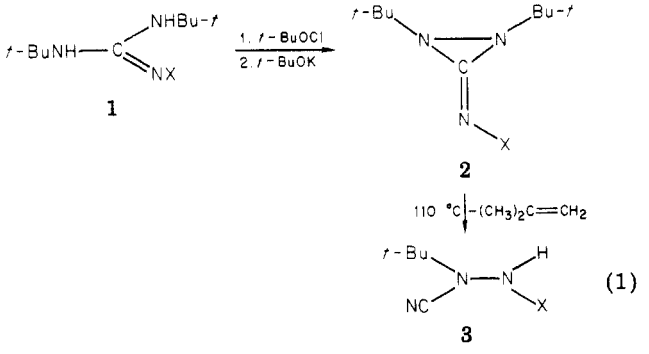
The conversion of guanidines into diaziridinimines on treatment with *t*-BuOCl and *t*-BuOK can be applied to the synthesis of sulfonyl-, phosphoryl-, and cyano-substituted derivatives bearing two additional *tert*-butyl groups. Carbethoxy- and benzoyl-substituted guanidines give *N*-carbonyl-substituted diaziridinimines only as elusive intermediates which rearrange into 5-imino-Δ^2-1,3,4-oxadiazolines. Other decomposition pathways observed are (i) rearrangement of sulfonylimino- and phosphorylimino-substituted diaziridines into hydrazine derivatives and (ii) cheletropic decomposition of *N*-cyano-substituted diaziridinimines into carbodiimides and cyanonitrene.

Diaziridinimines have been prepared by two methods developed by Quast and co-workers: (i) 1,3-dehydrohalogenation of *N*-chloroguanidines[1] and (ii) photolytic decomposition of trisubstituted tetrazolin-5-imines.[2] In all cases thus far studied only alkyl- and aryl-substituted derivatives have been obtained.[3] An interesting property of these compounds is their thermal decomposition into isonitriles and azo compounds.[1] If the same decomposition pathway were followed for acyl-, carbethoxy-, tosyl-, phosphoryl-, and cyano-substituted diaziridinimines, this would lead to the corresponding isonitriles which are only known for *N*-acyl derivatives.[4] This aspect prompted us to investigate the possibility of synthesizing functionalized diaziridinimines and to examine their thermal behavior.[5] The results are described in this paper.

Treatment of the substituted guanidines **1a–c** with *tert*-butyl hypochlorite and potassium *tert*-butoxide furnished the diaziridinimines **2a–c** in good yields (eq 1).



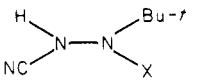
1 2 3 (1)

a, X = Ts; b, X = O=P(OPh)$_2$; c, X = O=P(OEt)$_2$

They were identified by their strong and broad C=NX stretching vibrations in the IR spectra; i.e., at 1750 cm^{-1} for **2a**, 1775 cm^{-1} for **2b**, and 1785 cm^{-1} for **2c**. These frequencies are higher than those for four- (ca. 1630–1650 cm^{-1})[6] and five-membered rings (ca. 1530 cm^{-1})[7] but lower than those for alkyl-substituted diaziridinimines (ca. 1790 cm^{-1}).[1]

In the ^{1}H and ^{13}C NMR room temperature spectra of **2a–c** ($CDCl_3$), the two *tert*-butyl groups are identical. At a lower temperature (−6 °C), the *tert*-butyl groups of **2a** become magnetically nonequivalent and give rise to two singlets. This is caused by restricted isomerization at the C=N double bond.[8] From the maximum chemical shift separation ($\Delta\nu$ = 24 Hz) and the temperature of coalescence (T_c = 23 °C) the free energy of activation $\Delta G^{\ddagger}_c$ was determined to be 15.0 kcal/mol. In the cases of **2b** and **2c**, no splitting of the *tert*-butyl signals is observed on lowering the temperature down to −50 °C.

Thermolysis of **2a,b** in refluxing toluene yielded the hydrazine derivatives **3a,b** instead of the anticipated isonitriles and azo compounds. Isobutene has been eliminated during thermolysis as evidenced by the presence of only one *tert*-butyl group in the ^{1}H NMR and ^{13}C NMR spectra. The spectral data, however, do not allow us to distinguish between the two isomeric structures **3** and **4**,



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but the exact structure of **3a** has been elucidated by a crystal structure determination.[9] Since the *tert*-butyl protons of **3b** (δ 1.15) resonate at almost the same position as those of **3a** (δ 1.22), we assume that the two thermolysis products have similar substitution patterns.

The formation of **3a,b** can be discussed in terms of several pathways. One of these takes a route identical with that of the alkyl-substituted diaziridinimines with formation of the corresponding isonitriles and azo compounds in the primary stage of the reaction. The tosyl and phosphoryl isonitriles would then rearrange to the more stable nitriles and add to the azo compounds, yielding **3a,b** after elimination of isobutene. However, in the absence of any evidence, it is questionable whether these nitriles would be reactive toward sterically hindered azo compounds.

A more plausible mechanism involves valence isomerization of **2** into the hydrazine as illustrated in Scheme I (route a) for the tosyl derivative. The hydrazine **5** then eliminates isobutene by a cyclic mechanism with participation of the tosyl group. A similar elimination on the other *tert*-butyl group is rendered unlikely by the linear structure of the nitrile function.

A third mechanistic possibility involves the valence isomers **6** and **7** as shown in Scheme I by route b. This

(1) H. Quast and E. Schmitt, *Angew. Chem.*, 81, 428 (1969); *Angew Chem., Int. Ed. Engl.*, 8, 448 (1969).
(2) H. Quast and L. Bieber, *Angew. Chem.*, 87, 422 (1975); *Angew. Chem., Int. Ed. Engl.*, 14, 428 (1975).
(3) Review: G. L'abbé, *Angew. Chem.*, 92, 277 (1980); *Angew. Chem., Int.Ed. Engl.*, 19, 276 (1980).
(4) G. Höfle and B. Lange, *Angew. Chem.*, 89, 272 (1977); *Angew. Chem., Int. Ed. Engl.*, 16, 262 (1977).
(5) For a preliminary report, see G. L'abbé and A. Verbruggen, *Tetrahedron Lett.*, 49 (1979).
(6) A. Van Camp, D. Goossens, M. Moya-Portuguez, J. Marchand-Brynaert, and L. Ghosez, *Tetrahedron Lett.*, 3081 (1980).
(7) G. L'abbé, G. Verhelst, C.-C. Yu, and S. Toppet, *J. Org. Chem.*, 40, 1728 (1975).
(8) For a review on syn–anti isomerism, see Q. Sutherland *Annu. Rep. NMR Spectrosc.*, 4, 186–192 (1971).
(9) J.-P. Declercq, G. Germain, and M. Van Meerssche, unpublished results.

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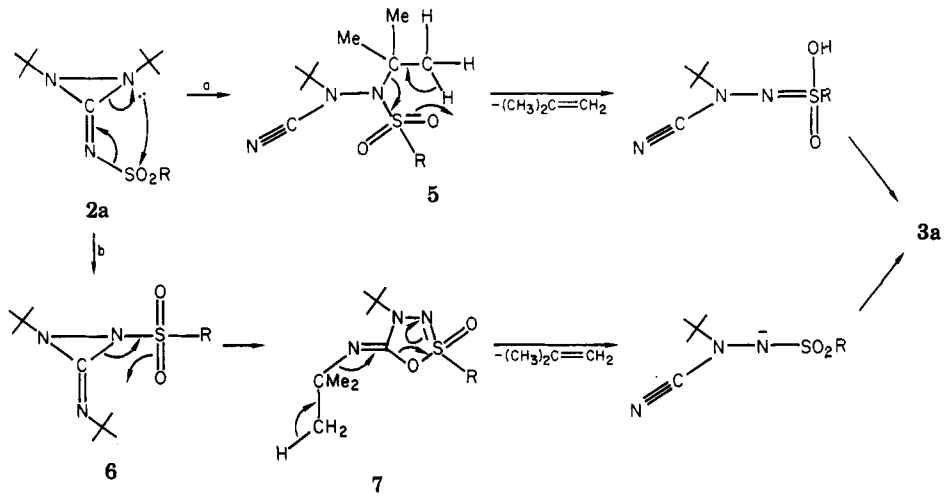
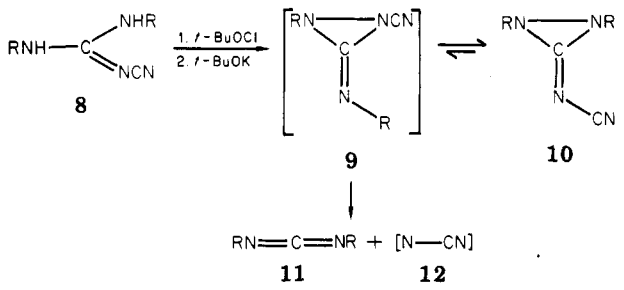
Scheme I

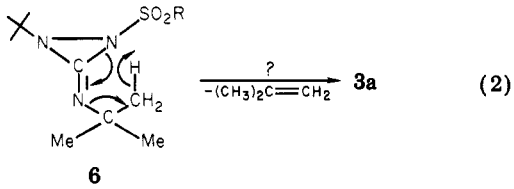


Scheme II[a]



[a] a, R = $C(CH_3)_3$; b, R = $(CH_3)_2CH$.

path is in line with the results discussed below for the cyano- and carbonyl-substituted derivatives (cf. structures **9** and **15**) and, hence, may be considered as the most likely at this moment. Another possibility is the direct conversion of **6** to **3a** by elimination of isobutene (eq 2), although the role of the SO_2R group in this process is not evident. Tri-*tert*-butyldiaziridinimines do not shown this property.[1]



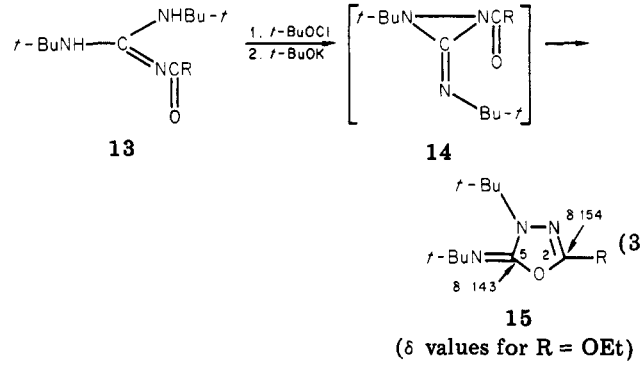
(2)

We have also examined the possibility of converting the cyanoguanidines **8a,b** into the cyanodiaziridinimines **10a,b** by successive treatment with *tert*-butyl hypochlorite and potassium *tert*-butoxide. When the reaction of **8a** was carried out in the usual manner at 0 °C, both **10a** (2210 and 1765 cm^{-1}) and **11a** (2160 cm^{-1}) were identified in the mixture by IR (Scheme II). Separation of these products proved to be difficult and could only be achieved at the expence of loss of much material. However, at −75 °C a clean reaction occurred, giving **10a** as the major product isolated in 82%. The ^1H NMR spectrum ($CDCl_3$) of **10a** at −20 °C shows two sharp signals for the *tert*-butyl groups ($\Delta\nu$ = 7 Hz) which are temperature dependent. They coalesce at 23 °C, corresponding to $\Delta G^{\ddagger}_c$ = 15.7 kcal/mol.

In contrast with **8a**, the isopropyl derivative **8b** did not yield the diaziridinimine **10b** but furnished **11b**, diisopropylurea (hydrolysis product of **11b**), and cyanamide. The latter probably results from the nitrene **12** by hydrogen abstraction. Thermolysis of **10a** at 100 °C also yielded the carbodiimide **11a** in addition to several unidentified products (mostly polymeric).

In order to explain these results, we postulate the intermediacy of **9** which can undergo two competitive reactions, i.e., valence isomerization into **10** and cheletropic decomposition into carbodiimide and cyanonitrene.[10] Attempts to trap **12** by adding dimethyl sulfide to the reaction mixture were unsuccessful.

N-Carbethoxy- and *N*-acyl-substituted diaziridinimines (**16**) could not be obtained by oxidative cyclization of the corresponding guanidines **13a,b**; instead, 5-imino-Δ^2-1,3,4-oxadiazolines **15a,b** were isolated in excellent yields.[11] This reaction involves a rearrangement occurring at the three-membered ring **14** (eq 3), which is postulated as an intermediate.[12] Nonsterically hindered *N*-alkyl-*N'*-(carboalkoxy)guanidines react analogously.[13]



a, R = OEt; b, R = Ph

The ^1H NMR spectra of the products reveal the presence of two *tert*-butyl singlets whose positions are not affected by raising the temperature up to 110 °C. In the ^{13}C NMR spectra, the C_5 atoms resonate at δ 143/145 in sharp con-

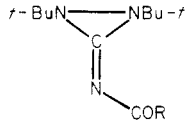
(10) For a review on cyanonitrene, see A. G. Anastassiou, H. E. Simmons, and F. D. Marsh In "Nitrenes", W. Lwowski, Ed., Interscience, New York, 1970, pp 305–344.

(11) For a review on 1,3,4-oxadiazoles, see A. Hetzheim and K. Möckel, *Adv. Heterocycl. Chem.*, 7, 183 (1966).

(12) For a similar rearrangement of acylated α-lactam intermediates, see: A. R. Gagneux and R. Göschke, *Tetrahedron Lett.*, 5451 (1966); H. Göth, A. R. Gagneux, C. H. Eugster, and H. Schmid, *Helv. Chim. Acta*, 50, 137 (1967); T. H. Kinstle and L. J. Darlage, *J. Heterocycl. Chem.*, 6, 123 (1969); H. Böshagen and W. Geiger, *Chem. Ber.*, 103, 123 (1970). Acylated aziridinimines behave similarly, see: F. De Sarlo, A. Guarna, P. Mascagni, R. Carrié, and P. Guenot, *J. Chem. Soc., Perkin Trans. 1*, 1367 (1981).

(13) G. L'abbé, G. Verhelst, S. Toppet, J.-P. Declercq, G. Germain, and M. Van Meerssche, *Bull. Soc. Chim. Belg.*, 87, 493 (1978).

trast with the ring carbon absorptions of **2** (δ 158–160) and **10a** (δ 165). Furthermore, the C=O carbon absorptions of **13a** (δ 163.5) and **13b** (δ 176.6) have shifted upfield to respectively δ 154.3 and 151.4 in the products. These facts have led us to reject **16** but left us with two alternative structures, **15** and **17**. The latter would be formed by



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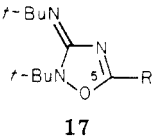

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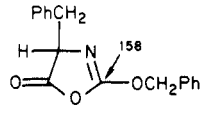
intramolecular cyclization of the chlorinated form of **13** by way of the carbonyl function, analogous to dehydrohalogenation of *N*-acyl- and *N*-carbethoxy-substituted α-chloroamides and α-haloamidines into Δ^2-oxazolin-4-ones and 4-amino-Δ^3-oxazolin-2-ones, respectively.[14]

In order to differentiate between **15** and **17**, we have compared the ^{13}C NMR data of **15a** with those of the model compounds **18–21** from the literature.[15] The pertinent δ values are given on the drawings. The C_2 resonance of **15a** is found at a comparable position to that of **18**. On the other hand, the corresponding carbon resonances of **19** and **20** are shifted considerably downfield, due to the extended conjugation. The same type of conjugation is present in structure **17**, which would thus have a C_5 absorption at about δ 170. On the basis of this argument, structure **17** is rejected. It is also noteworthy that **15a** is similar to structure **21** with similar ring carbon absorptions and IR stretching vibrations, i.e., at 1725 and 1660 cm^{-1}.



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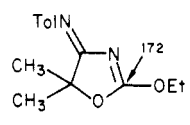

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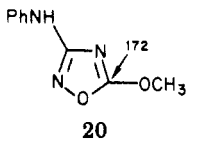

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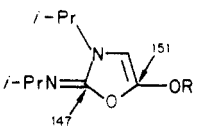
(Me$_2$SO-d_6 as solvent)



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Experimental Section

The starting materials **1a**,[16] **1b,c**,[17] **8a,b**[18] and **13a,b**[17] were prepared by standard procedures described in the literature.

Oxidative Cyclization of the Guanidines. [(1,2-Di-*tert*-butyl-3-tosyl)imino]diaziridine (**2a**) was synthesized by using the method of Quast and Schmitt:[1] yield 85%; mp 80–81 °C (*n*-hexane); IR (KBr) 2980, 1750 (s, br, C=N), 1320 and 1160 cm^{-1} (SO_2); ^1H NMR ($CDCl_3$) δ 1.25 (br, 18 H), 2.4 (s, 3 H), 7.35 and 7.85 (2 d, 4 H); ^{13}C NMR ($CDCl_3$) δ 21.5 (*p*-CH_3), 26.8 (CH_3), 62.1 (CMe_3), 127.2 and 129.7 (aromatic CH), 138.5 and 144.1 (aromatic C_1 and C_p), 157.9 (ring C); mass spectrum, *m/e* (relative intensity) 323 (2, $M^{+\cdot}$), 267 (20, $M^{+\cdot}$ – $Me_2C{=}CH_2$), 211 (6, $M^{+\cdot}$ – $2Me_2C{=}CH_2$), 168 (60), 155 (34, Ts^+), 91 (90, $C_7H_7^+$). Anal. Calcd for $C_{16}H_{25}N_3O_2S$ (mol wt 323): C, 59.41; H, 7.79; N, 12.99. Found: C, 59.42; H, 7.71; N, 13.14.

For the other compounds the following general procedure was used. To a solution of guanidine (3–8 mmol) in 60 mL of CCl_4 (THF in the cases of **8a,b**) was added successively with stirring 2–3 equiv of *tert*-butyl hypochlorite and potassium *tert*-butoxide at 0 to −20 °C (−75 °C in the cases of **8a,b**). After a reaction time of 10–30 min (3 h in the case of **8a**), the mixture was allowed to come to room temperature and filtered. The filtrate was evaporated and the residue subjected to column chromatography on silica gel.

1,2-Di-*tert*-butyl-3-[(diphenoxyphosphoryl)imino]diaziridine (**2b**) was obtained as a pale yellow oil in 60% yield (90% before purification): IR (neat) 2970, 1775 cm^{-1} (s, br, C=N); ^1H NMR ($CDCl_3$) δ 1.22 (s, 18 H), 7.0–7.3 (m, 10 H); ^{13}C NMR ($CDCl_3$ at −50 °C) δ 26.6 (CH_3), 61.3 (CMe_3), 120.5, 125.4 and 129.9 (aromatic CH), 150.4 (d, aromatic C_1), 160.2 (ring C); mass spectrum, *m/e* (relative intensity) 401 (21, $M^{+\cdot}$), 345 (3, $M^{+\cdot}$ – $Me_2C{=}CH_2$), 275 (34, $(PhO)_2P(O)N{\equiv}CNH_2^+$), 249 (100, $(PhO)_2P(O)NH_2$), 94 (41, $PhOH^{+\cdot}$), 77 (76, $C_6H_5^+$); Calcd for $M^{+\cdot}$ (determined by high-resolution exact-mass measurement) *m/e* 401.1868, found *m/e* 401.1874.

1,2-Di-*tert*-butyl-3-[(diethoxyphosphoryl)imino]diaziridine (**2c**) was obtained as an oil in 57% yield: IR (neat) 2970, 1785 cm^{-1} (s, br, C=N); ^1H NMR ($CDCl_3$) δ 1.22 (s, 18 H), 1.2–1.5 (m, 6 H, $2CH_3$), 4.0–4.4 (m, 4 H, $2CH_2$); ^{13}C NMR ($CDCl_3$) δ 15.9 (d, CH_3), 26.5 (CH_3), 60.4 (CMe_3), 62.7 (d, CH_2), 157.3 (ring C); mass spectrum, *m/e* (relative intensity) 305 (16, $M^{+\cdot}$), 249 (35, $M^{+\cdot}$ – $Me_2C{=}CH_2$), 234 (43, $M^{+\cdot}$ – $Me_2C{=}CH_2$ – Me), 179 (55, $(EtO)_2P(O)N{\equiv}CNH_2^+$), 164 (100, *m/e* 179 – Me), 136 (62); calcd for $M^{+\cdot}$ (determined by high-resolution exact-mass measurement) *m/e* 305.1857, found *m/e* 305.1864.

Note that after isolation, **2b** and **2c** were considered to be pure by TLC and ^1H NMR, but they slowly decomposed on standing at room temperature.

1,2-Di-*tert*-butyl-3-(cyanimino)diaziridine (**10a**) was obtained as colorless crystals in 65% yield (82% before crystallization): mp 42–43.5 °C (petroleum ether); IR (KBr) 2210 (s, C≡N), 1765 (s, br, C=N); ^1H NMR ($CDCl_3$) δ 1.24 (s, 18 H); ^{13}C NMR ($CDCl_3$) δ 27.0 (CH_3), 62.5 (CMe_3), 113.0 (C≡N), 165.2 (C=N); mass spectrum, *m/e* (relative intensity) 194 (0.8, $M^{+\cdot}$), 154 (27, $M^{+\cdot}$ – NCN), 139 (31, $M^{+\cdot}$ – NCN – Me), 83 (95, $Me_2CN{=}C{=}NH^+$), 57 (100, $C_4H_9^+$). Anal. Calcd for $C_6H_9N_4$ (mol wt 194): C, 61.81; H, 9.36; N, 28.84. Found: C, 61.62; H, 9.37; N, 28.96.

The reaction of **8b** with *tert*-butyl hypochlorite and potassium *tert*-butoxide gave *N,N'*-diisopropylcarbodiimide (15%), diisopropylurea (10%), unreacted **8b** (22%), and a viscous oil in which the presence of cyanamide was demonstrated by TLC.

2-Ethoxy-4-*tert*-butyl-5-(*tert*-butylimino)-Δ^2-1,3,4-oxadiazoline (**15a**) was obtained as a colorless oil in 73% yield: IR (neat) 2980, 1725 (s br, C=N), 1655 cm^{-1} (s, C=C); ^1H NMR ($CDCl_3$) δ 1.24 (s, 9 H), 1.42 (s, 9 H), 1.42 (t, 3 H), 4.25 (q, 2 H); ^{13}C NMR ($CDCl_3$) δ 14.3 (CH_3CH_2), 27.4 and 30.8 ($2CH_3$), 52.9 and 57.8 ($2CMe_3$), 143.2 (s, C_5), 154.3 (t, C_2); mass spectrum, *m/e* (relative intensity) 241 (4, $M^{+\cdot}$), 185 (3, $M^{+\cdot}$ – $Me_2C{=}CH_2$), 170 (7, *m/e* 185 – Me), 129 (19, $M^{+\cdot}$ – $2Me_2C{=}CH_2$), 57 (100, $C_4H_8^{+\cdot}$). Anal. Calcd for the picrate (mp 142–143 °C) $C_{18}H_{26}N_6O_9$ (mol wt 470): C, 45.95; H, 5.53; N, 17.82. Found: C, 45.82; H, 5.53; N, 17.77.

2-Phenyl-4-*tert*-butyl-5-(*tert*-butylimino)-Δ^2-1,3,4-oxadiazoline (**15b**) was obtained as a pale yellow oil in 80% yield; IR (neat) 2960, 1690 cm^{-1} (s, br, C=N); ^1H NMR ($CDCl_3$) δ 1.36 (s, 9 H), 1.56 (s, 9 H), 7.3–7.8 (2m, 5 aromatic H); ^{13}C NMR ($CDCl_3$) δ 27.7 and 30.6 ($2CH_3$), 53.7 and 59.2 ($2CMe_3$), 125.5, 129.1, and 130.7 (aromatic C), 145 (C_5), 151.4 (C_2); mass spectrum, *m/e* (relative intensity) 273 (24, $M^{+\cdot}$), 217 (47, $M^{+\cdot}$ – $Me_2C{=}CH_2$), 202 (100, *m/e* 217 – Me), 161 (93, $M^{+\cdot}$ – $2Me_2C{=}CH_2$), 107 (15, $PhCO^+$). Anal. Calcd for $C_{16}H_{23}N_3O$ (mol wt 273): C, 70.33; H, 8.42. Found: C, 70.25; H, 8.33.

Thermolysis of the Diaziridinimines. A toluene solution of **2a** (1 g in 5 mL) was refluxed for 5 h. When the solution was cooled, **3a** crystallized out in 58% yield: mp 176–177 °C (benzene); IR (KBr) 3130 (s, NH), 2980, 2220 cm^{-1} (s, CN); ^1H NMR ($CDCl_3$) δ 1.22 (s, 9 H), 2.42 (s, 3 H), 7.1 (NH, exchangeable with D_2O), 7.3 and 7.8 (2d, 4 H); ^{13}C NMR ($CDCl_3$) δ 21.8 (*p*-CH_3), 26.3 (CH_3), 62.4 (CMe_3), 113.5 (C≡N), 129 and 130.5 (aromatic CH), 134 and

(14) (a) Y. S. Rao and R. Filler, *Chem. Commun.*, 1622 (1970); (b) N. Götz and B. Zeeh, *Synthesis*, 268 (1976); (c) G. L'abbé, A. Verbruggen, and S. Toppet, *Bull. Soc. Chim. Belg.*, **90**, 99 (1981).

(15) See ref 14b and W. J. Kauffman, *J. Org. Chem.*, **35**, 4244 (1970); J. H. Jones and M. J. Witty, *J. Chem. Soc., Chem. Commun.*, 281 (1977); J. Drapier, A. Feron, R. Warin, A. J. Hubert, and P. Teyssié, *Tetrahedron Lett.*, 559 (1979).

(16) W. V. Farrar, *J. Chem. Soc.*, 856 (1965).

(17) R. Neidlein and E. Heukelbach, *Arch. Pharm. (Weinheim)*, **299**, 709 (1966). See also F. Kurzer and K. Douraghi-Zadeh, *Chem. Rev.*, **67**, 107 (1967).

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145.8 (aromatic C_1 and C_p); mass spectrum, m/e (relative intensity) 267 (10, $M^{+\cdot}$), 211 (50, $M^{+\cdot} - Me_2C{=}CH_2$), 155 (33, Ts^+), 91 (45, $C_7H_7^+$), 57 (100). Anal. Calcd for $C_{12}H_{17}O_2N_3S$ (mol wt 267): C, 53.91; H, 6.41; N, 15.72. Found: C, 53.89; H, 6.29; N, 15.83.

Thermolysis of **2b** (0.3 g) in 0.5 mL of toluene at 110 °C was completed within 15 h. The solvent was removed, and the residue was crystallized from ether–petroleum ether to give **3b** in 77% yield: mp 147–148 °C; IR (KBr) 3120 (s, NH), 2200 cm^{-1} (s, CN); ^1H NMR ($CDCl_3$) δ 1.15 (s, 9 H), 7.1–7.4 (m, NH and 10 aromatic H); ^{13}C NMR ($CDCl_3$) δ 26.3 (CH_3), 61.0 (d, CMe_3, $^3J_{CP}$ = 4.5 Hz), 115.2 (C≡N), 120.6 and 130.1 (aromatic CH), 150.9 (aromatic C_1); mass spectrum, m/e (relative intensity) 345 (6, $M^{+\cdot}$), 289 (100, $M^{+\cdot} - Me_2C{=}CH_2$), 105 (12), 94 (35, $PhOH^{+\cdot}$), 77 (24, $C_6H_5^+$). Anal. Calcd for $C_{17}H_{20}N_3O_3P$ (mol wt 345): C, 59.13; H, 5.80; N, 12.17. Found: C, 58.95; H, 5.85; N, 12.14.

A toluene solution of **10a** (0.28 g in 1 mL) was heated in an NMR tube at 100 °C for 3 h. Then, the solvent was removed in vacuo, and the residue was subjected to preparative TLC on silica gel, giving di-*tert*-butylcarbodiimide in 18% yield.

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Registry No. 1a, 739-31-1; **1b**, 78822-71-6; **1c**, 78822-72-7; **2a**, 70406-90-5; **2b**, 78822-73-8; **2c**, 78822-74-9; **3a**, 70388-51-1; **3b**, 78822-75-0; **8a**, 78822-76-1; **8b**, 78822-77-2; **10a**, 78822-78-3; **13a**, 78822-79-4; **13b**, 78822-80-7; **15a**, 78822-81-8; **15a** picrate, 78822-83-0; **15b**, 78822-82-9; *N,N'*-diisopropylcarbodiimide, 693-13-0; diisopropylurea, 4128-37-4; di-*tert*-butylcarbodiimide, 691-24-7.

Synthesis of Sulfur-Containing Macrocycles Using Cesium Thiolates

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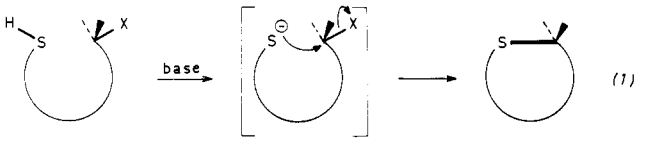
In dimethylformamide (DMF) solution 1,ω-dithiols are deprotonated by cesium carbonate. Reaction with 1,ω-dibromide in the same solvent leads to excellent yields of the corresponding macrocyclic (di)sulfides. The reaction is normally carried out by adding the dithiol (4×10^{-2} M in DMF) and dibromide (4×10^{-2} M in DMF) simultaneously to a 10% excess of cesium carbonate (8.8×10^{-3} M suspended in DMF) at 45–50 °C over a period of 12–15 h. In this fashion there was obtained, for example, 1,12-dithiacyclododocosane (**1d**) in 85% yield from the reaction of decane-1,10-dithiol with 1,10-dibromodecane. Other compounds obtained from the combination $HS(CH_2)_mSH$ and $Br(CH_2)_nBr$ are **1a** (m = 3, n = 4), **1b** ($m = n$ = 5), **1c** (m = 5, n = 10), **1e** (m = 10, n = 16), **1f** ($m = n$ = 10), and **1g** (m = 16, n = 18) in yields ranging from 45 to 90%. By means of the same approach using various 1,ω-dithiols and *o*-xylene α,α'-dibromide, a series of macrocycles was prepared in yields ranging from 64–88%. Various thia crown ether compounds have been prepared as well as ligands like 1,4,8,11-tetrathiacyclotetradecane (**15**), prepared from 3,7-dithianonane-1,9-dithiol and 1,3-dibromopropane in 76% yield as compared to the literature yield of 7.5%. This ability of cesium to promote ring closure appears to be unique certainly in cases where long chains devoid of heteroatoms are involved. This method makes available a variety of sulfur-containing ligands and the potential for scaling up the reaction has also been demonstrated.

Examples of macrocycles containing one or more sulfide linkages[1] include thia crown ethers[2] and cryptates,[3] sulfur-containing cyclophanes,[4] ligands of defined shape and bonding properties for complexing metal ions,[2,3,5] or compounds useful for examination of, for example, sulfur–sulfur bonding or electron transfer between sulfur atoms.[6] The sulfide linkage occurs also in some macrocyclic natural products.[7] There are broad aspects of interest for macrocyclic sulfur compounds, and the potential applications, although many, are relatively unexplored.

The limitation in studying such compounds is in many cases a synthetic one. Acute difficulties can be encountered if the ring closure must be accomplished by the logical synthetic route of S_N2 ring closure by means of a thiolate anion attacking an activated carbon (usually primary) as shown in the generalized formula of eq 1.



(1)

A rough generalization is that syntheses involving as final step ring closure as depicted in eq 1 can be carried

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