Tetrahedron Vol. 39, No. 12, pp. 2065 to 2071, 1983
Printed in Great Britain.

0040-4020/83 $3.00 + .00

REACTIONS OF NITROGEN CONTAINING AROMATIC ANIONS WITH CHLOROCARBENE[1]

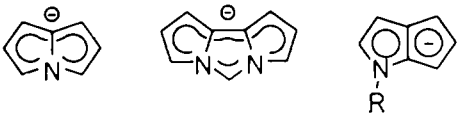
U. BURGER* and F. DREIER
Department of Organic Chemistry, University of Geneva, 1211 Geneva 4, Switzerland

(*Received in USA 24 June* 1982)

Abstract—It is shown that the 4-azapentalene anion (**1**) and the dipyrrolo[1,2c:2′,1′e]imidazolyl anion (**2**) (Li salts) undergo eliminative ring fission upon reaction with chlorocarbene in tetrahydrofuran. Acetylenes (**12** and **18**) are the result. The reaction of **1** is accompanied by ring enlargement to indolizine (**7**). When the reaction of **1** with chlorocarbene is performed in diethylether, again **7** is produced, this time accompanied by a tetracyclic valence isomer, the pyrroloazabenzvalene (**8**). Mechanistic implications, based on the finding that the site of label incorporation in the enlarged products is solvent dependent, are discussed and compared with the corresponding reactions of carboaromatic anions. Use of intramolecular oxidative coupling for the synthesis of new pyrrolo annellated heterocyclic systems is made throughout this work.

Ring expansions of heterocyclic compounds by reaction with halocarbenes have been known for many decades.[2] Most studies and applications in this area, however, have dealt with electrically neutral, i.e. non-ionic substrates. To our knowledge, reactions of halocarbenes with N-containing aromatic anions have not been examined in detail. This is in marked contrast to the amount of work done in the corresponding chemistry of carboaromatic anions. The formation of tricyclo[3.1.0.0^{2,6}]hexene-3 (benzvalene)[3] and of several benzo annelated derivatives thereof,[4] by reaction of Li salts of appropriate cyclopentadienides with chlorocarbene, constitutes an interesting and by now well known chapter of more recent carbene chemistry. It is the purpose of this study to shed some light on that gap and to unveil the influence of the heteroatom on reaction paths.

Although there is only a limited number of N-containing aromatic anions known, they show with respect to their electronic structures a larger variety than their carbocyclic counterparts. At one extreme,



1 2 3

4 5

exemplified by the 4-azapentalene anion (**1**)[5] and by the dipyrrolo[1,2c:2′,1′e]-2H-imidazolide (**2**)[1b] we encounter these species where the negative charge resides within the aromatic π-system. They have no extra pairs of free electrons at the heteroatom, and the conjugate acids of these anions are C–H acids. At the other extreme, represented by the pyrryl anion (**5**), we find ions where the negative charge is localized at the heteroatom in a free pair of electrons outside of the aromatic π-system. The conjugate acids of these species are N–H acids. A borderline situation is encountered with pyrindinide (**4**)[6] which has an extra pair of electrons at the heteroatom, but nevertheless it carries the negative charge in the aromatic π-system. Anion **4** and the N-alkyl-3-azapentalene anion (**3**)[7] can be regarded as cyclopentadienide annellated to pyridine and N-alkylpyrrole, respectively. Therefore both anions, **3** and **4** will presumably react with chlorocarbene much in the same way as indenide[3] (*vide infra*).

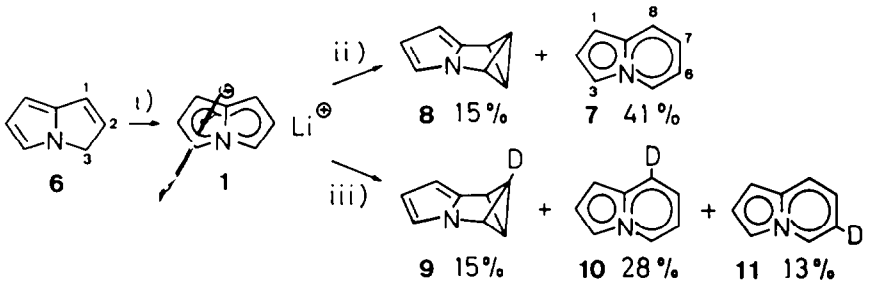
The ions where the heteroatom can have a major influence on reactivity towards chlorocarbene clearly are compounds **1** and **2**; therefore our investigations will be primarily concerned with these.

The experiments we describe have been performed under homogeneous conditions in ether-type solvents, e.g. dimethyl, diethyl ether or tetrahydrofuran (THF), with Li being the counterion of the aromatic substrates. Although formulas of free ions are used in the schemes, counterion association of yet unknown extent should be tacitly admitted. Formal chlorocarbene is obtained from methylene chloride and alkyllithium.[8] Often therefore we can not state whether we are dealing with free carbene or carbenoid chemistry;[9] but sometimes, as will be shown, we can.

RESULTS

3H-Pyrrolizine (**6**)[10] in diethyl ether was converted to its moderately soluble lithium salt (**1**)[5] by reaction with n-BuLi. Further reaction with chlorocarbene gave two isomeric compounds: indolizine (**7**; 41%) and pyrrolo-3-azabenzvalene (**8**; 15%).[1a] Repetition of the experiment with dideuteromethylene chloride gave in addition to 1-d-pyrrolo-3-azabenzvalene (**9**) two isotopomers of monodeuteroindolizine (**10** and **11**) in a 2:1 ratio (Scheme 1).

Performing the reaction of **1** with n-BuLi/methylene chloride in THF instead of diethyl ether produced a profound change of events. Instead of the bicyclobutane derivative (**8**), a monocyclic isomer, **cis**-1-[α-pyrryl]but-1-ene-3-yne (**12**)[1a] is obtained in 31% yield. It is accompanied again by formation of indolizine (**7**; 38%). Still more surprising than the ring

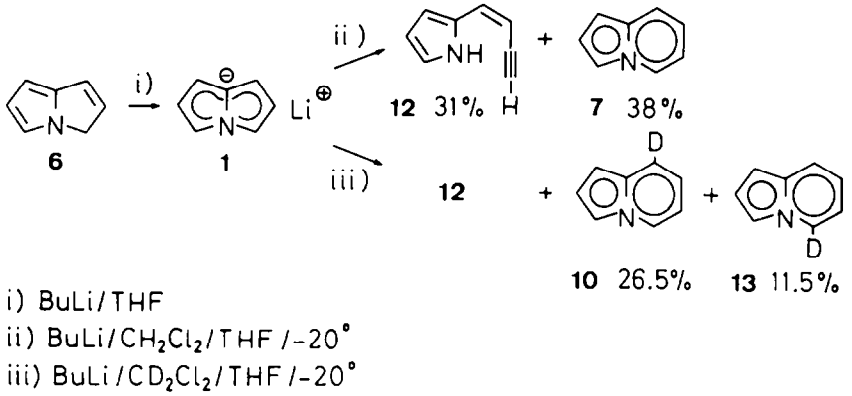


Scheme 1.

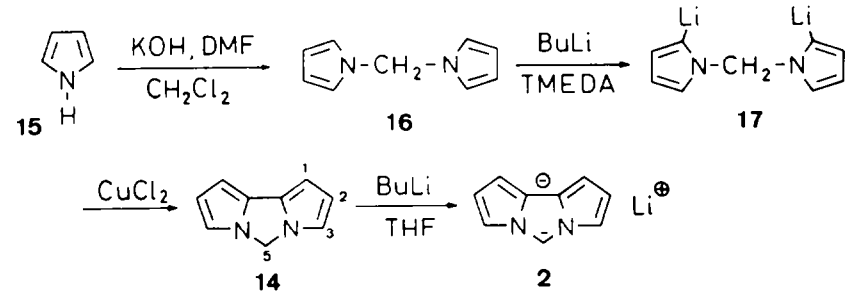
opening is the result of the labelling experiment performed with dideuteromethylene chloride (Scheme 2). The label now is found in the indolizine positions C-8 (**10**) and C-5 (**13**) instead of C-6. The ratio is 2.3:1. The bicyclobutane derivative (**8**) was not observed to undergo ring-opening to give **12** when subjected to the reaction conditions of Scheme 2 (step ii).

Dipyrrolo[1.2c:2′,1′e]2H-imidazole (**14**), the conjugate acid of **2**, has recently been prepared in our laboratory.[1b] An efficient route to its synthesis is outlined in Scheme 3. The initial step consists in the formation of N,N′-dipyrrolylmethane (**16**). The latter has previously been obtained from pyrryllithium or potassium and methylene chloride in hexamethylphosphoric triamide[1b] or liquid ammonia.[11] We now found that **16** can be obtained in high yield (96%) under phase transfer conditions (PTC)[12] by simply stirring pyrrole with methylene chloride in dimethylformamide (DMF) over solid potassium hydroxide. No phase transfer catalyst is required. Metallation of **16** by treatment with 2.2 equivalents of n-BuLi in benzene/tetramethylethylene diamine (TMEDA) occurs predominantly (> 80%) in the 2,2′ positions (**17**), as verified by quenching experiments with D_2O. Ring-closure is finally achieved in 35% yield by intramolecular oxidative coupling[13] with copper(II) chloride (Scheme 3). Nickel(II) chloride, which was used successfully in the intermolecular coupling of N-alkylpyrroles[13c] gave somewhat lower yields in our hands. Reaction of **14** with n-BuLi in THF gave the soluble lithium salt **2** in nearly quantitative yield. The latter, unfortunately, is almost insoluble in diethyl or dimethyl ether.

The heterogeneous reaction of **2** (Li salt) with chlorocarbene in diethyl ether gave an intractable



Scheme 2.



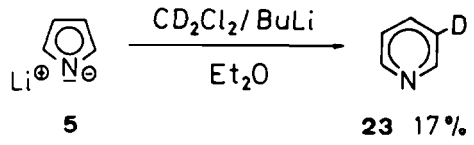
Scheme 3.

mixture of products in low yield, but proceeded smoothly in THF. In this solvent, i.e. under homogeneous conditions, **2** reacts with methylene chloride/n-BuLi to give N-ethynyl-α,α′-bipyrrole (**18**) in 47% yield. In contrast to the corresponding reaction of the 4-azapentalene anion (**1**), no ring expansion to dipyrrolo[1.2a:2′.1′c]pyrazine (**19**) is observed. In order to make this finding unambiguous and to test the stability of **19** under the reaction conditions, we have synthesized the as yet unreported **19** by an alternative route (Scheme 4).

The key step of this synthesis is an intramolecular oxidative coupling similar to the strategy of Scheme 3. 1,2-N,N′-Dipyrrolylethane (**20**) required for the purpose had previously been obtained by synthesizing the two pyrrole moieties around the N atoms of ethylene diamine.[14] We have now found that pyrrole (**15**) reacts in dimethyl sulfoxide (DMSO) with excess ethylene ditosylate (**21**) over solid KOH to give **20** in acceptable yield (43%). The reaction is conveniently run at 65°. At room temperature N-*p*-tolylsulfonylpyrrole,[15] resulting from attack at the S atom of **21**, is found to be an important byproduct. At higher temperature, however, this undesired product cleaved, thereby recycling the pyrrole moiety in favor of the formation of **20**.

Cyclization of **20** by treatment with n-BuLi and copper(II) chloride in benzene/TMEDA gave dipyrrolo[1.2a:2′.1′c]-5,6-dihydropyrazine (**22**) in 34% yield. Dehydrogenation, finally, was achieved by melting **22** over Pd–C *in vacuo*. Compound **19** is stable under the conditions of the formation of **18** from **2**.

We have examined briefly the reaction of pyrryllithium (**5**) with chlorocarbene. In diethylether, pyridine was the only product found in low yield (17%). Deuterium incorporation from dideuteromethylene chloride occurred in the β-position exclusively (**23**) (Scheme 5). Thus the modestly soluble salt **5** reacts similarly to free pyrrole.[16,2b]



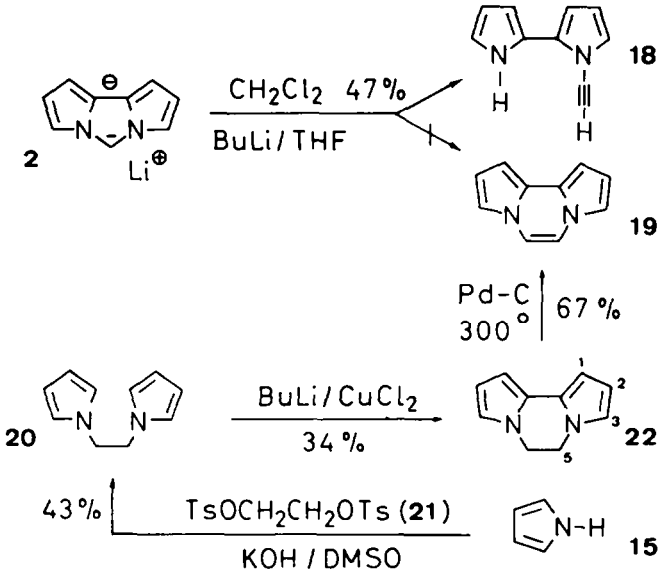
5 **23** 17%

Scheme 5.

DISCUSSION

When labelled carbene was used, the site and extent of labelling in the enlarged products was found to be solvent-dependent. On one occasion we obtained a bicyclobutane derivative, on others the reaction of heteroaromatic anions resulted in the formation of acetylenes. Is there a mechanistic model that can account for all of these observations, and allow further predictions to be made?

Let us consider an allyl anion reacting with chlorocarbene (Scheme 6). Other than for the corresponding reaction of a neutral π-substrate (e.g. the chlorocyclopropanation of ethylene), we have to expect the initial formation of only one new C–C bond, a homoallylchlorocarbanion (**24**), or the corresponding lithiumcarbenoid will be the result. This intermediate (**24**) may react further in a variety of ways. It can complete the cyclopropanation to give **25** in a reaction that is well known to be reversible.[17] More-importantly, **24** has the possibility to undergo α-elimination, thereby producing a new carbene, i.e. the allylcarbene **26**. This α-elimination will be particularly efficient in such solvents that do not stabilize carbenoids.†



Scheme 4.

†To our knowledge the reaction of the allyl anion with chlorocarbene has not yet been studied. The products obtained from the reaction of 3-cyclohexenyllithium with methylene chloride and n-BuLi suggest that 3-cyclohexenylcarbene (corresponding to **26**) is a key intermediate of the principal reaction path. However, due to the particularly low oxidation potential of the cyclohexenyl anion, a single electron transfer producing the 3-cyclohexenyl radical competes with the carbene reaction in this case.[18a]

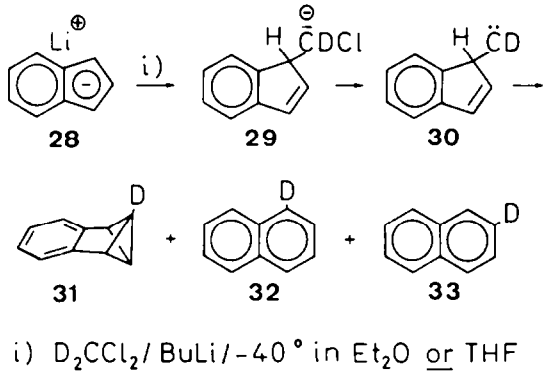
Let us now assume that the starting allyl anion has a leaving group ($-X$), which for one reason or another ends up in the β-position of the homoallylchlorocarbanion (**24**). Then, this intermediate has a further option to react: β-elimination producing 1-chlorobutadienes (**27**) (Scheme 6).

The expectations outlined here for allyl anions can be extended without major modifications to larger negative π-systems and also to aromatic anions. All products obtained from the reaction of chlorocarbene with aromatic anions result either from the α-elimination route via the corresponding allylcarbene derivative (**26**) or from the β-elimination route via a chlorobutadiene derivative (**27**).

Let us consider for illustration the reaction of the Li salt of indene (**28**).[3] Here the situation is simple in so far as the intermediate homoallylchlorocarbanion (**29**) has no suitable leaving group ($-X$) in the β-position. The α-elimination route to give the carbene **30** is the only reaction open to **29**, regardless of whether we work in a carbenoid stabilizing or destabilizing solvent. Both the reactions in diethyl ether and in THF give identical products in similar ratios.† As is suggested by the labelling experiment[18b] summarized in Scheme 7, benzobenzvalene (**31**) results from the intramolecular ring-closure of the carbene **30** whereas the two isotopomeric naphthalene molecules (**32** and **33**) are the products of its phenyl and vinyl shift, respectively.

The corresponding reaction of the 4-azapentalene anion **1** is more complicated. In diethyl ether (Scheme 1) there is a resemblance to the indenide example, the major difference being that **1** has two chemically different sites, C-1 and C-3, where initial C–C bond formation can occur. This, qualitatively, is seen from the results of simple Hückel MO theory[19] depicted in Fig. 1. The coefficients of the HOMO of **1** at the centers C-1 and C-3 are equal within this model, and the excess charges are nearly the same (-0.29 vs -0.24). Regardless therefore of whether the initial C–C bond formation occurs under charge or orbital control, one might expect little site selectivity.

The labelling experiment indeed suggests that two different allyl carbenes (**35** and **37**) are formed (Scheme 8). Attack at C-1 of the starting heteroaromatic anion **1** gives **35** and accounts for the ultimate formation of 8-deuteroindolizine (**10**)



Scheme 7.

whereas attack at C-3 gives **37** which by virtue of a vinyl shift expands to 6-deuteroindolizine (**11**). The bicyclobutane **9**, again, results from the intramolecular carbene addition.

A priori, both intermediates **35** and **37** are candidates for the formation of **9**. One must keep in mind however that the intramolecular carbene addition, like its intermolecular counterpart, will be efficient only if the HOMO coefficients of the double bond involved are large. Interestingly, the two intermediates **35** and **37** differ greatly in this respect. Even a very rough estimate (HMO, Fig. 2) shows that the coefficients in question are large only for **37** but not at all for **35**. Therefore we assume **37** to be the principal or possibly the exclusive precursor of the bicyclobutane **9**.

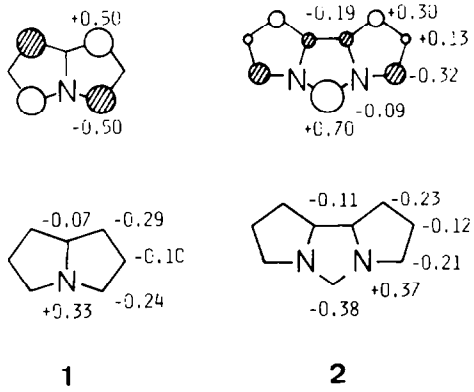
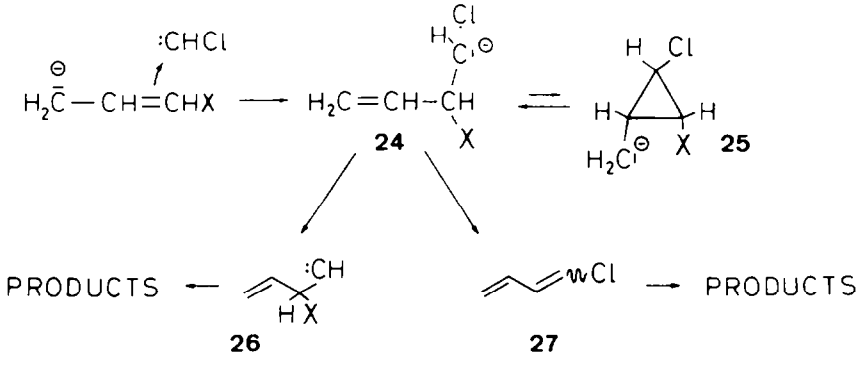
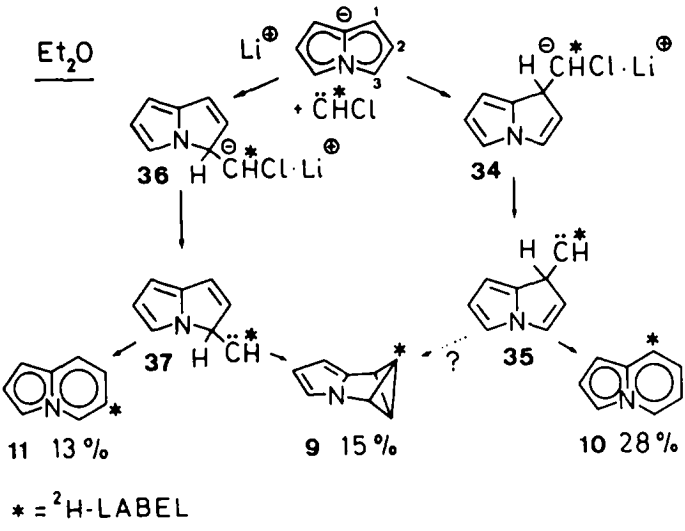


Fig. 1. Coefficients of the HOMO (top row) and excess charge distribution (bottom row) of the anions **1** and **2** according to HMO theory.[19]

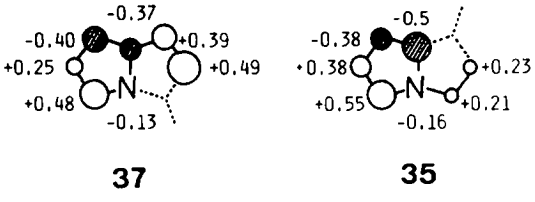
†We found the following product distribution: in Et_2O **31** (12%), **32** (9%) and **33** (15%), in THF **31** (11%), **32** (12%) and **33** (36%). These data are obtained by ^{2}H-FT-NMR analysis at 55.3 MHz.



Scheme 6.



Scheme 8.

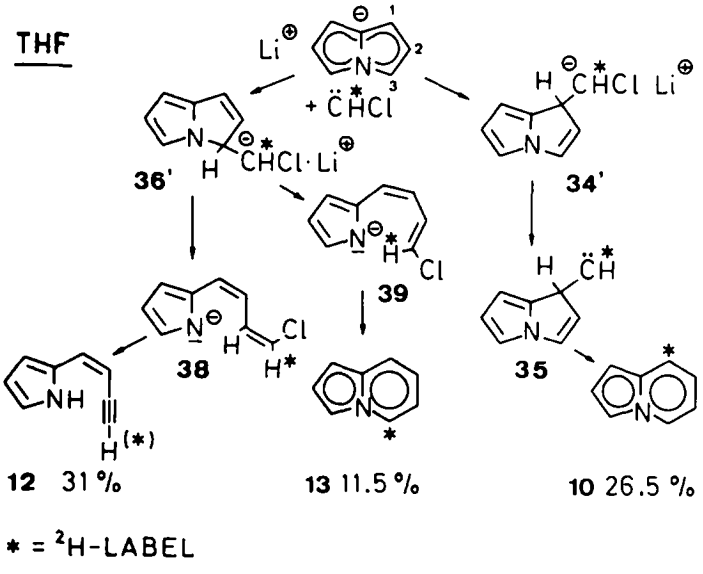


37 35

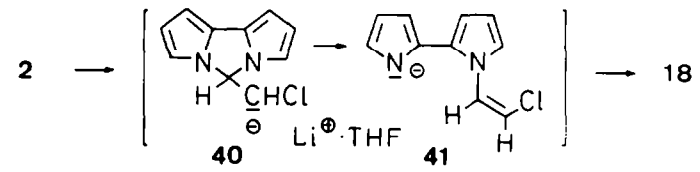
Fig. 2. HOMO coefficients of the olefinic moieties of carbenes **35** and **37** according to HMO theory.

In the reaction of **1** with labelled chlorocarbene in THF (Scheme 9) we encounter initial C–C bond formation at positions C-1 and C-3. Attack at C-1 leads to the same result that was obtained in diethyl ether, i.e. the carbenoid **34′** has no alternative choice other than to undergo α-elimination, giving carbene **35** and thus 8-deuteroindolizine **10**. More revealing is the initial attack of chlorocarbene at C-3 of **1**. The resulting allylchlorocarbanion (or carbenoid) **36′** now has an ideal leaving group in its β-position, i.e. the pyrryl anion moiety. Two isomeric chlorobutadiene derivatives **38** and **39** result from the eliminative ring fission.[20] The *Z,Z*-isomer (**38**) has the correct stereochemistry for further loss of HCl. It therefore is the principal source of the acetylene **12**. The deuterium label is lost from the terminal acetylenic position during the aqueous work-up procedure. The *Z,E*-isomer **39**, however, having no hydrogen atom *trans* co-planar to chlorine, gives 5-deuteroindolizine (**13**) by way of an intramolecular addition elimination reaction.

After the discussion of the reactions and labelling experiments performed with the 4-azapentalene anion (**1**), the behavior of dipyrroloimidazolide (**2**) is more readily understood. A glance at the electronic properties (Fig. 1) shows that ion **2** has a single site where an electrophile will attack, i.e. the central carbon atom C-5. It has by far the largest excess of charge (−0.38) and the HOMO of the ion has a big



Scheme 9.



Scheme 10.

coefficient at this center (0.7). Clearly, formation of the chlorocarbanion (or carbenoid) **40** will result from the reaction with chlorocarbene (Scheme 10).

THF being the solvent, **40** has the choice to eliminate either of the enantiotopic pyrryl moieties. Possibly this eliminative ring fission gives selectively the *Z*-β-chlorovinyl derivative **41**, which then further reacts to the acetylene **18**. Unfortunately, the product balance is too low (47%) to allow for a safe statement at this point. It is recalled, however, that no bipyrrolopyrazine (**19**) is formed in the reaction. So there is no analogy for the sequence **36′→39→13** of Scheme 9.

In summary, the reactions of heteroaromatic anions with chlorocarbene, though complex, allow for a deep insight into mechanistic details and provide a valuable complement to the corresponding chemistry of carboaromatic substrates.

EXPERIMENTAL

General remarks. ^{1}H-NMR spectra (δ |ppm| relative to internal TMS. Multiplicity: s = singlet, d = doublet, t = triplet, m = multiplet; J|Hz| = coupling constant): Varian XL-100 spectrometer (100.1 MHz) or Bruker WM-360 spectrometer (360 MHz). ^{2}H-NMR spectra (δ |ppm| relative to internal CD_2Cl_2 (δ = 5.32); proton coupled; FT mode without field frequency stabilization): Bruker WM-360 spectrometer (55.3 MHz). ^{13}C-NMR spectra (δ |ppm| relative to internal TMS; multiplicity for off-resonance decoupling: s = singlet, d = doublet, t = triplet): Varian XL-100 spectrometer (25.2 MHz) or Bruker WM-360 spectrometer (90.56 MHz). Mass spectra (MS) (*m/z* relative intensity), m* = metastable peak: Varian MAT-SMA spectrometer (70 eV). Gas chromatography (GC): Carlo-Erba Fractovap model 2150 (glass columns, N_2-carrier).

All operations with n-BuLi and MeLi were carried out in Schlenk tubes under argon. The normality of n-BuLi in hexane (Merck) and of MeLi in diethylether (Merck) was determined immediately prior to use by Gilman's double titration method.[21]

Reaction of pyrrolizinyl lithium (**1**) *with* CD_2Cl_2/BuLi *in diethyl ether* (*cf* Ref. 1*a*). 20 ml (30 mmole) of a 1.5 M soln of BuLi in hexane are added under argon at −78° to the soln of 1.0 g (9.5 mmole) of freshly distilled **6**[10] in 40 ml dry diethyl ether. The mixture is allowed to briefly reach room temp and then is re-cooled under stirring to −20°. After drop by drop addition of 1.3 ml (20 mmole) of CD_2Cl_2 (Merck, 99.5% grade) the mixture is kept at −20° for another 15 mins and then hydrolyzed with 2N NH_4Cl soln. The organic layer, after rapid washing with 2N NH_4Cl followed by water, is dried over a 2:1 mixture of $MgSO_4/Na_2CO_3$. The solvent is removed and the products are prepurified by flash distillation at 10^{-4} Torr. An aliquot dissolved in CH_2Cl_2 is examined by ^{2}H-FT-NMR at 55.3 MHz. It shows next to a small signal of residual CD_2Cl_2 (δ |ppm| 5.32) three absorptions (~singlets of 20 ± 3 Hz width at half height) at δ |ppm| 3.16, 6.46 and 7.37 in a 0.5 : 0.4 : 1 ratio. Based on the 1:1 relationship of ^{1}H and ^{2}H chemical shifts,[22] this corresponds to compounds **9**, **11** and **10**, respectively. The indolizine (mixture of isotopomers) is isolated by preparative GC (silicon SE-30, 10% on chromosorb, 6 m glass column, 125°). ^{1}H-NMR integration (at 360 MHz) and the changes in the coupling pattern as compared to authentic indolizine (**7**),[23] confirm the presence of the two isotopomers **11** and **10** and their 0.4:1 ratio. Compound **9**, which did not survive the preparative GC procedure, was enriched to 70% (accompanied by **10** and **11**) by repeated distillation (−20° to +10°/10^{-4} Torr). Comparison of its ^{1}H-NMR spectrum with that of the unlabelled **8**[1a] confirmed the structure **9**.

Reaction of pyrrolizinyl lithium (**1**) *with* CD_2Cl_2/BuLi *in* THF (*cf* Ref. 1*a*). The reaction is carried out as the preceding one, THF, however, being used instead of ether. After hydrolysis with 2N NH_4Cl soln, the organic products are taken up in ether, washed as before and dried over $MgSO_4/Na_2CO_3$ (2:1). After removal of the solvents the crude products are prepurified by flash distillation at 10^{-4} Torr. An aliquot dissolved in CH_2Cl_2 is examined by ^{2}H-FT-NMR. It shows, next to small non-identified resonances, two strong signals (~singlets of 20 ± 3 Hz width at half height) at δ |ppm| 7.37 and 7.95 in a 1:0.43 ratio. This corresponds to the indolizine positions C-8 (**10**) and C-5 (**13**). Samples of both the labelled indolizine and pyrrylbutenyne (**12**) were isolated by preparative GC (silicon SE-30, 10% on chromosorb, 6 m glass column, 125°). Compound **12** elutes before indolizine. ^{1}H-NMR analysis at 360 MHz confirmed the presence of indolizines **10** and **13** and their 1:0.43 ratio. No deuterium however was found in the pyrrylbutenyne. Its ^{1}H-NMR and MS was identical with those of unlabelled material.[1a]

N,N′-*Dipyrrolylmethane* (**16**) (PTC procedure). 11.2 g (0.2 mole) of KOH pellets are covered with 100 ml anhyd DMSO. 4.15 ml (60 mmole) of freshly distilled pyrrole is added and the mixture stirred for 1 hr. The mixture is brought to 40°, then 3 ml (46 mmole) of CH_2Cl_2 are added slowly. The mixture is stirred at 40° for 4 hr, hydrolyzed under ice cooling by addition of 100 ml each of water and ether. The aqueous layer is extracted with ether (3 × 75 ml). The combined organic phase is washed with 3 × 100 ml water, followed by sat NaCl aq, and dried over $MgSO_4$. 4.3 g (96%) of crude crystalline **16** remain after removal of the solvent *in vacuo*. It can be recrystallized from CCl_4. **16**: m.p. 105°. Spectroscopic data see Ref. 1*b*.

Oxidative coupling **16→14** see Ref. 1*b*

N-*Ethynyl*-α,α′-*bipyrrole* (**18**) *from* **2**. 30 mmole of BuLi in 20 ml of dry THF (prepared by solvent exchange in the Schlenk tube) are mixed at −78° under argon with a soln of 1.45 g (10 mmole) of **14**[1b] in 40 ml dry THF. The mixture is allowed to reach room temp for 2 hr. After re-cooling to −20°, 1.3 ml (20 mmole) of CH_2Cl_2 are added slowly. After 30 min the mixture is hydrolyzed with 2N NH_4Cl soln, taken up in 100 ml ether, washed (2 × 50 ml sat NaCl aq) and dried ($MgSO_4/Na_2CO_3$, 2:1). The crude product remaining after removal of the solvents is purified by column chromatography (silica gel, hexane–ether, 4:1). Yield of **18** after chromatography 733 mg (47%). No **19** is detected by chromatography nor by ^{1}H-NMR in the crude products. Compound **18**: colorless crystals, m.p. 144–146°. MS ($C_{10}H_8N_2$, 156): 156 (100) (M^+), 155 (34), 129 (11), 128 (11), 80 (9). IR ($CHCl_3$) |cm^{-1}|: 3440 (m) N–H. 3285 (m)≡C–H, 2940 (s) C–H aromatic, 2145 (m) C≡C. ^{1}H-NMR ($CDCl_3$, 100 MHz): 3.00 (s, 1H, acetylenic); 6.2–6.35 [complex m, 4H, H-C(3), H-C(3′), H-C(4) and H-C(4′)]: 6.8–6.9 [complex m, 2H, H-C(5) and H-C(5′)]; 8.5 (broad s, 1H, H-N).

Dipyrrolo[1,2*a*:2′,1′*c*]*pyrazine* (**19**). A mixture of 300 mg (1.9 mmole) of **22** with 300 mg Pd–C (10%) is sealed under vacuum (10^{-2} Torr) in a thick-walled pyrex tube and kept at 300° for 5 hr. The cold residue is extracted with benzene (2 × 20 ml) and purified by column chromatography (Al_2O_3 basic, hexane–ether, 4:1). 10% of starting material **22** are recovered. Yield of **19** 198 mg (67%). **19**: colorless crystals, m.p. 79–80°. MS ($C_{10}H_8N_2$, 156): 156 (100) (M^+), 155 (48), 129 (17), 128 (13), 102 (9), 78 (12), 51 (17). ^{1}H-NMR ($CDCl_3$, 360 MHz): 6.5–6.55 [narrow ABM type m, 4H, H-C(1) + H-C(2) and H-C(9) + H-C($\overline{10}$), $^3J_{1,2}$ = 3.7 Hz]; 6.98 [sym. ABM type m, 2H, H-C(3) + H-C(8)], 7.05 (s, 2H, H-C(5) + H-C(6)). ^{13}C-NMR ($CDCl_3$, 90.56 MHz): 99.47 [d, C(2), C(9)]; 111.4 [d, C(1), C(10)]; 111.6 [d, C(5), C(6)]; 114.6 [d, C(3), C(8)]; 124.5 [s, C(10a), C(10b)].

1,2-N,N′-*Dipyrrolylethane* (**20**) (PTC procedure). 5.85 g (104 mmole) of KOH pellets are covered with 100 ml of anhyd DMSO. 174 g (26 mmole) of pyrrole are added with stirring. After 3 hr the mixture is brought to 65° and 15 g (40 mmole) of **21** are added in 10 portions in intervals of 10 min. The mixture is stirred at 65° for 5 hr, then cooled, hydrolyzed, and extracted with ether (3 × 150 ml). The organic phase is washed successively with water, sat $CuSO_4$ aq, water, sat NaCl aq, and then dried over $MgSO_4$. Distillation (120–130°/10^{-3} Torr) of the reddish oil remaining after removal of the solvent gives 0.89 g (43%) of crystalline **20**. This can be further purified by recrystallization from little ether. **20**: colorless crystals, m.p. 107–108° (lit.[14] 107.5–108°). The product is identical (IR, ^{1}H-NMR, ^{13}C-NMR) with an authentic sample.[14]

Dipyrrolo[1,2*a*:2′,1′*c*]-5,6-*dihydropyrazine* (**22**). A soln of 1.0 g (6.25 mmole) of **20** in 60 ml benzene and 2 ml TMEDA is allowed to react for 24 hr at room temp under argon with 20 ml (18 mmole) of a 0.9N soln of BuLi in benzene. This mixture is added under vigorous stirring to a suspension of 1.68 g (12.5 mmole) anhyd $CuCl_2$ in 100 ml benzene. After 5 hr the mixture is hydrolyzed, filtered, and exhaustively extracted with ether. The organic layer is dried over $MgSO_4$ and the solvent removed under vacuum. The crude product is purified by column chromatography (Al_2O_3 basic, hexane–ether, 4:1). Yield 340 mg (34%). Compound **22**: colorless crystals, m.p. 86–87°. MS ($C_{10}H_{10}N_2$, 158): 158 (62) (M^+), 134 (24), 130 (64), 117 (10), 106.9 (m*), 104 (46), 79 (100). ^{1}H-NMR ($CDCl_3$, 360 MHz): 4.22 [s, 4H, H-C(5) and H-C(6)]; 6.19 [dd, 2H, H-C(2) and H-C(9), $^3J_{2,1}$ = 4 Hz, $^3J_{2,3}$ = 2.5 Hz]; 6.28 [dd, 2H, H-C(1) and H-C(10), $^4J_{1,3}$ = 1.5 Hz]; 6.61 [dd, 2H, H-C(3) and H-C(8)]. ^{13}C-NMR ($CDCl_3$, 90.56 MHz): 44.36 [d, C(5), C(6)]; 102.1 [d, C(2), C(9)]; 108.9 [d, C(1), C(10)]; 118.8 [d, C(3), C(8)]; 125.6 [?, s, C(10a), C(10b)].

Acknowledgements—We are indebted to Messrs. R. Etienne and J.-P. Saulnier for technical assistance. Financial support by the Swiss National Science Foundation (project No. 2.455-0.79) is gratefully acknowledged.

REFERENCES

[1]For preliminary communications of part of the results see [a]U. Burger and F. Dreier, *Helv. Chim. Acta* **62**, 540 (1979); [b]U. Burger and F. Dreier, *Ibid.* **63**, 1190 (1980).

[2a]C. W. Rees and C. E. Smithen, *Adv. Heterocycl. Chem.* **3**, 57 (1964); [b]H. C. Van der Plas, *Ring Transformation of Heterocycles*, Vol. 1, p. 210. Academic Press, New York (1973); [c]F. De Angelis, A. Gambacorta and R. Nicoletti, *Synthesis* 798 (1976); [d]E. V. Dehmlow and K. Franke, *Liebigs Ann. Chem.* 1456 (1979).

[3]T. J. Katz, E. J. Wang and N. Acton, *J. Am. Chem. Soc.* **93**, 3782 (1971).

[4a]R. M. Pagni and C. R. Watson, Jr., *Tetrahedron Letters* 59 (1973); [b]I. Murata and K. Nakasuji, *Ibid.* 53 (1973); [c]G. Gandillon B. Bianco and U. Burger, *Ibid.* **22**, 51 (1981); [d]U. Burger, G. Gandillon and J. Mareda, *Helv. Chim. Acta* **64**, 844 (1981).

[5]W. H. Okamura and T. J. Katz, *Tetrahedron* **23**, 2941 (1967).

[6]G. A. Anastassiou, E. Reichmanis and S. J. Girgenti, *J. Am. Chem. Soc.* **99**, 7392 (1977).

[7a]H. Volz, U. Zirngibl and B. Messner, *Tetrahedron Letters* 3593 (1970); [b]H. Volz and R. Draese, *Ibid.* 4917 (1970).

[8]G. L. Closs and L. E. Closs, *J. Am. Chem. Soc.* **81**, 4996 (1959); **82**, 5723 (1960).

[9a]G. Köbrich, *Angew. Chem.* **84**, 557 (1972); [b]D. Seebach, H. Siegel, J. Gabriel and R. Hässig, *Helv. Chim. Acta* **63**, 2046 (1980) and Refs therein.

[10a]E. E. Schweizer and K. K. Light, *J. Am. Chem. Soc.* **86**, 2963 (1964); [b]E. E. Schweizer and K. K. Light, *J. Org. Chem.* **31**, 870 (1966).

[11]N. D. Scott, *US Pat.* 2,488,336 (1949) to E. I. du Pont de Nemours; *Chem. Abstr* **44**, 1544e (1950).

[12]*Cf* [a]H. Heaney and S. V. Ley, *J. Chem. Soc.* Perkin I 499 (1973); [b]W. C. Guida and D. J. Mathre, *J. Org. Chem.* **45**, 3172 (1980); [c]E. V. Dehmlow and S. S. Dehmlow, *Phase Transfer Catalys.* Verlag Chemie, Weinheim (1980).

[13a]N. Gjos and S. Gronowitz, *Acta Chem. Scand.* **25**, 2596 (1971); [b]T. Kauffmann, *Angew. Chem.* Int. Ed. Engl. **13**, 291 (1974); [c]T. Kauffmann and H. Lexy, *Chem. Ber.* **114**, 3674 (1981).

[14]M. F. Fegley, N. M. Bortnick and C. H. McKeever, *J. Am. Chem. Soc.* **79**, 4144 (1957).

[15]E. P. Papadopoulos and N. F. Haider, *Tetrahedron Letters* 1721 (1968).

[16]G. L. Closs and G. M. Schwartz, *J. Org. Chem.* **26**, 2609 (1961).

[17a]D. J. Patel, C. L. Hamilton and J. D. Roberts, *J. Am. Chem. Soc.* **87**, 5144 (1965); [b]A. Maercker and K. Weber, *Ann. Chem.* **756**, 43 (1972); [c]A. Maercker and R. Geuss, *Chem. Ber.* **106**, 773 (1973).

[18a]U. Burger, *Chimia* **33**, 147 (1979); [b]U. Burger and F. Mazenod, *Tetrahedron Letters* 2881 (1976).

[19]Standard perturbation operators for heteroatoms were taken from A. Streitwieser, Jr., *Molecular Orbital Theory for Organic Chemists*, p. 135. Wiley, New York (1962).

[20]C. J. M. Stirling, *Chem. Rev.* **78**, 517 (1978).

[21]R. G. Jones and H. Gilman, *Org. React.* **6**, 632 (1951).

[22]H. H. Mantsch, H. Saitô and I. C. P. Smith, *Progress in NMR Spectroscopy*, Vol. 11, p. 211. Pergamon Press, Oxford (1977).

[23a]V. Boekelheide and R. J. Windgassen, Jr., *J. Am. Chem. Soc.* **81**, 1456 (1959); [b]R. J. Pugmire, M. J. Robins, D. M. Grant and R. K. Robins, *Ibid.* **93**, 1887 (1971).