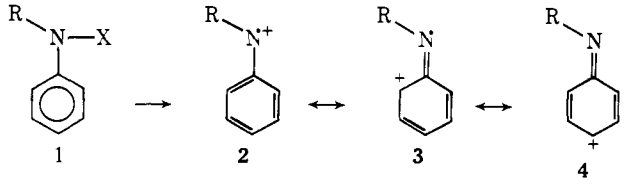
Nucleophilic Aromatic Substitution of Anilines *via* Aryl Nitrenium Ions (Anilenium Ions)[1]

Paul G. Gassman,* Gerald A. Campbell,[2] and Ronald C. Frederick

Contribution from the Department of Chemistry, The Ohio State University, Columbus, Ohio 43210. *Received October 1, 1971*

Abstract: The generation of phenyl-substituted nitrenium ions from *N*-chloroanilines in a silver ion promoted solvolytic process is described. A series of *N*-chloroanilines has been synthesized and their methanolysis has been studied in the presence of silver trifluoroacetate. The products obtained from these solvolyses differ greatly, depending on the nature of the substituents on the aromatic ring. For simple, electron-rich *N*-chloroanilines, which are not substituted in the para position, the major process involved formation of anisidines. For electron-rich *N*-chloroanilines substituted in the para position with carbonium ion stabilizing groups the principle products were derivatives of 2,5-cyclohexadienone. When strong electron-withdrawing substituents are situated on the aromatic ring of the *N*-chloroaniline, the major reaction pathway became ring chlorination. The mechanistic details of these synthetically useful transformations are discussed. In general, it is proposed that the formation of anisidines, derivatives of 2,5-cyclohexadienone, and ring-chlorinated anilines involves the initial formation of a highly delocalized phenylnitrenium ion (anilenium ion).

While electrophilic aromatic substitution has been shown to provide a versatile route to a broad spectrum of substituted aromatic molecules, nucleophilic aromatic substitution has been generally limited in scope to aromatic systems which were abundantly functionalized with strong electron-withdrawing substituents and to aromatic diazonium salts.[3] The almost exclusive nature of the electrophilic and nucleophilic aromatic substitution processes can be observed for a variety of aromatic compounds including simple derivatives of phenol and aniline. In these examples, the electron-donating ability of the heteroatom (through resonance) results in the possibility of nucleophilic aromatic substitution being remote. However, in view of the well-established acid-catalyzed rearrangements of arylhydroxylamines,[4] it seemed probable that the presence of a suitable leaving group on the heteroatom could result in a positively charged species being generated, which, through charge delocalization, would render the aromatic nucleus vulnerable to nucleophilic attack. For instance, we felt that heterolytic cleavage of the N–X bond of **1**, under solvolytic conditions, would lead to a phenylnitrenium ion (anilenium ion) represented by the resonance contributors **2**, **3**, and **4**.



1 **2** **3** **4**

Consideration of the relative electronegativities of nitrogen and carbon indicated that considerable charge delocalization into the ring should occur. This would make the ring very susceptible to nucleophilic attack. With these concepts in mind, we embarked on the detailed study of the generation of anilenium ions which is described in this paper.[5]

The first problem to be solved was the choice of a suitable leaving group. The extensive investigation of nitrenium ion chemistry previously reported from our laboratories[6] indicated that chloride was probably the best choice, since *N*-chloramines are readily prepared in almost quantitative yield through treatment of the appropriate secondary amine with calcium hypochlorite, sodium hypochlorite, or *tert*-butyl hypochlorite. In addition, we had previously established that *N*-chloramines reacted with silver ion in polar solvents, such as methanol, to generate divalent positively charged nitrogen intermediates (nitrenium ions) and silver chloride.[6]

Although *N*-alkyl-*N*-chloroanilines had not been well characterized prior to this study, they had been postulated to be the reaction intermediates in the chlorination of aromatic amines,[7] and one example had been observed in solution.[8] We have found that *N*-chloroanilines are readily prepared from suitable *N*-alkylanilines *via* reaction of these anilines with calcium hypochlorite, sodium hypochlorite, or *tert*-butyl hypochlorite at temperatures ranging from −78 to 25°. In most cases the *N*-chloroanilines could be isolated, titrated for active chlorine,[9] and characterized spectroscopically. However, in a few cases the *N*-chloroanilines were extremely reactive and were generated and used *in situ* in subsequent reactions. Qualitative ob-

(1) Paper XXI in a series on The Chemistry of Nitrenium Ions. For the previous papers in this series see P. G. Gassman and G. A. Campbell, *J. Chem. Soc. D*, 1437 (1971); P. G. Gassman, G. Gruetzmacher, and R. H. Smith, *Tetrahedron Lett.*, 497 (1972); P. G. Gassman, K. Shudo, R. L. Cryberg, and A. Battisti, *ibid.*, 875 (1972).

(2) National Defense Education Act Fellow, 1967–1970; Stauffer Chemical Fellow, 1970–1971.

(3) For pertinent discussions of nucleophilic aromatic substitution, see (a) J. F. Bunnett and R. E. Zahler, *Chem. Rev.*, **49**, 273 (1951); (b) E. D. Hughes and C. K. Ingold, *Quart. Rev., Chem. Soc.*, **6**, 34 (1952); (c) J. F. Bunnett, *ibid.*, **12**, 1 (1958); (d) R. Saur and R. Huisgen, *Angew. Chem.*, 72, 294 (1960); (e) S. D. Ross, *Progr. Phys. Org. Chem.*, 1, 31 (1963).

(4) H. E. Heller, E. D. Hughes, and C. K. Ingold, *Nature (London)*, **168**, 909 (1951); see also R. A. Abramovitch and B. A. Davis, *Chem. Rev.*, **64**, 176 (1964).

(5) For preliminary reports of part of this work, see P. G. Gassman, G. A. Campbell, and R. C. Frederick, *J. Amer. Chem. Soc.*, **90**, 7377 (1968); and P. G. Gassman and G. A. Campbell, *J. Chem. Soc. D*, 427 (1970).

(6) For a review of these studies, see P. G. Gassman, *Accounts Chem. Res.*, **3**, 26 (1970).

(7) R. S. Neale, R. G. Schepers, and M. R. Walsh, *J. Org. Chem.*, **29**, 3390 (1964).

(8) P. Haberfield and D. Paul, *J. Amer. Chem. Soc.*, **87**, 5502 (1965).

(9) Titration for active chlorine involved the treatment of an acidified solution of the *N*-chloroaniline with potassium iodide, followed by titration of the liberated iodine with standard sodium thiosulfate solution.

Table I. Source and Preparation of *N*-Alkyl-*N*-chloroanilines

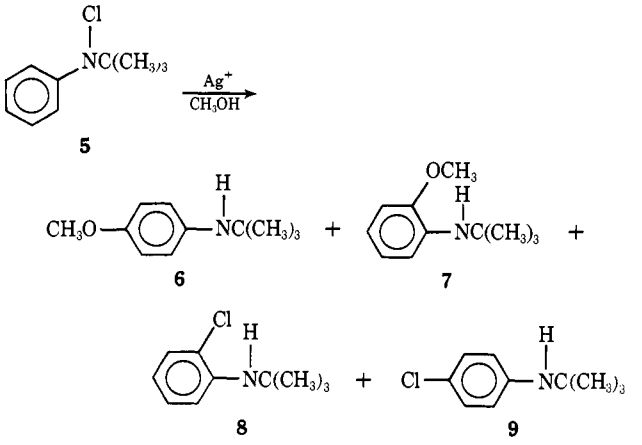
Precursor	Source of precursor	Chlorinating agent	Temp of chlorination, °C	Yield of chloroaniline, %
N-*tert*-Butylaniline	*a*	$Ca(OCl)_2$	−8	92[e]
N-Methylaniline	*b*	NaOCl	−8	89[e]
N-*tert*-Butyl-*o*-toluidine	*a*	*tert*-Butyl hypochlorite	−78	*f*
2,6,*N*-Trimethylaniline	*c*	*tert*-Butyl hypochlorite	−78	
N-Methyl-*o*-aminobiphenyl	*c*	*tert*-Butyl hypochlorite	−78	*f*
N-*tert*-Butyl-*p*-toluidine	*a*	$Ca(OCl)_2$	0	98[e]
N-*tert*-Butyl-*p*-aminobiphenyl	*a*	$Ca(OCl)_2$	0	85[g]
N-*tert*-Butyl-*p*-chloroaniline	*a*	$Ca(OCl)_2$	25	97[e]
Ethyl *p*-(*N*-*tert*-butylamino)benzoate	*a*	$Ca(OCl)_2$	25	96[e]
p-(*N*-*tert*-Butylamino)nitrobenzene	*d*	$Ca(OCl)_2$	25	95[g]

[a] Precursor was prepared from the appropriate aniline hydrochloride and *tert*-butyl alcohol. [b] Commercially available. [c] Precursor was prepared by hydride reduction of the corresponding formamide. [d] Precursor prepared from *p*-fluoronitrobenzene and *tert*-butylamine. [e] Yield based on titration of active chlorine. [f] Yield not determined due to extreme instability of the *N*-chloroaniline even at very low temperatures. [g] Yield based on isolated, crystallized *N*-chloroaniline.

servation indicated that the stability of the *N*-chloroanilines was a function of the substitution on the aromatic ring. Electron-donating substituents decreased the stability, while electron-withdrawing substituents increased the stability of the *N*-chloroanilines.[10] However, all of the *N*-chloroanilines used in this study were stable below −10°. The *N*-alkylanilines used as precursors of the *N*-alkyl-*N*-chloroanilines were derived from many sources. In general, the *N*-*tert*-butylanilines were prepared *via* the high-pressure reaction of the appropriate aniline hydrochloride with *tert*-butyl alcohol[11] or, in those cases where strong electron-withdrawing substituents were situated on the aromatic ring, by the nucleophilic displacement of the appropriately situated fluoride by *tert*-butylamine.[12] Table I lists the *N*-alkyl-*N*-chloroanilines which were prepared as part of this study, the source of the precursor, and the method of preparation of the *N*-alkyl-*N*-chloroaniline.

In the detailed study of Neale and coworkers,[7] it was demonstrated that chlorination of anilines with certain halogenating agents produced *o*- and *p*-chloroanilines with the ortho derivative predominating. Haberfield and Paul provided convincing evidence that chlorination of the aromatic nucleus was preceded by *N*-chlorination. Having available the *N*-chloroanilines listed in Table I, we chose to study their behavior in the presence of a good chloride scavenger. For this purpose we chose silver ion in the hope that silver chloride would precipitate from solution, leaving the initially generated cation vulnerable to nucleophilic attack by solvent.

When *N*-*tert*-butyl-*N*-chloroaniline (**5**) was treated with silver trifluoroacetate in methanol at −8° for 18 hr, a mixture was obtained which contained **6**, **7**, **8**, and **9** in yields of 39, 6, 28, and 6%, respectively, for a total yield of 79% based on unrecovered *N*-*tert*-butylaniline (which generally accounted for *ca.* 5–10% of **5**). The product ratio was relatively insensitive to the temperature of the reaction. When the cold solution of **5** was added to a refluxing solution of silver trifluoroacetate in methanol, the yields of **6**, **7**, **8**, and **9** were 35, 5, 22, and 6%, respectively. The formation of **6** as the major



product indicated the synthetic utility of the process. Since several steps would be required to *p*-methoxylate an aniline derivative by classical routes, this one-step process appears particularly attractive. In order to establish the generality of the *p*-methoxylation process, we studied the methoxylation of the four additional *N*-chloroanilines listed in Table II. In all five examples listed in Table II, para methoxylation was the major process. In the case of **10**, minor products were *N*-methyl-*o*-methoxyaniline (1%), *N*-methyl-*o*-chloroaniline (9%), and *N*-methyl-*p*-chloroaniline (6%). The lower yields observed for the reaction of **10**, relative to the analogous reaction of **5**, were due to the oxidation of the products from **10** by silver ion. The formation of metallic silver in the case of **10** provided ample evidence for the occurrence of such an oxidative process.

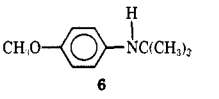
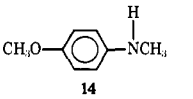
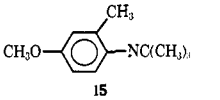
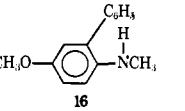
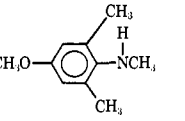
The formation of anisoles from *N*-chloroanilines in the presence of silver ion clearly required nucleophilic attack of solvent on the aromatic ring. In general, we feel that the mechanistic scheme shown for the formation of **6** from **5** could equally well be used to rationalize the formation of **14**, **15**, **16**, and **17** from **10**, **11**, **12**, and **13**, respectively. We envisage initial silver ion promoted ionization of **5** to produce the anilenium ion represented by resonance structures **18**, **19**, and **20**. Nucleophilic attack of methanol at the center of positive charge shown in **20**, with loss of a proton from the adduct, would lead to **21**. Hydrogen migration and accompanying rearomatization would then convert **21** into **6**. In the proposed mechanism, a critical step involved hydrogen migration and associated rearomatization. If a less readily migratable group were present in

(10) For a quantitative study of *N*-chloroaniline stability see P. G. Gassman and G. A. Campbell, *J. Amer. Chem. Soc.*, **93**, 2567 (1971); P. G. Gassman and G. A. Campbell, *ibid.*, **94**, 3891 (1972).

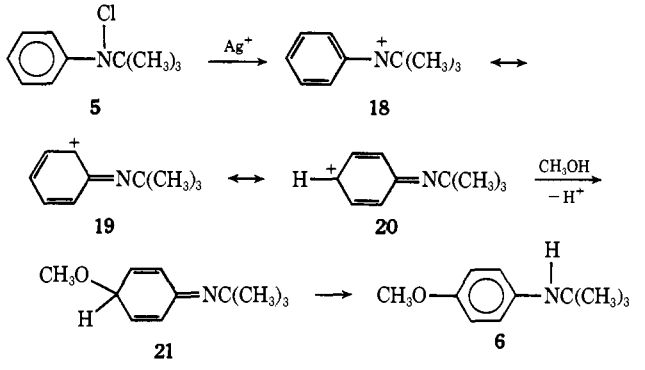
(11) A. Bell and M. B. Knowles, U. S. Patent 2,692,287 (1956); *Chem. Abstr.*, **50**, 2666*e* (1956).

(12) H. Suhr, *Justus Liebigs Ann. Chem.*, **687**, 175 (1961).

Table II. Yields of *p*-Anisole Derivatives Formed from the Silver Ion Promoted Solvolysis of *N*-Chloroanilines

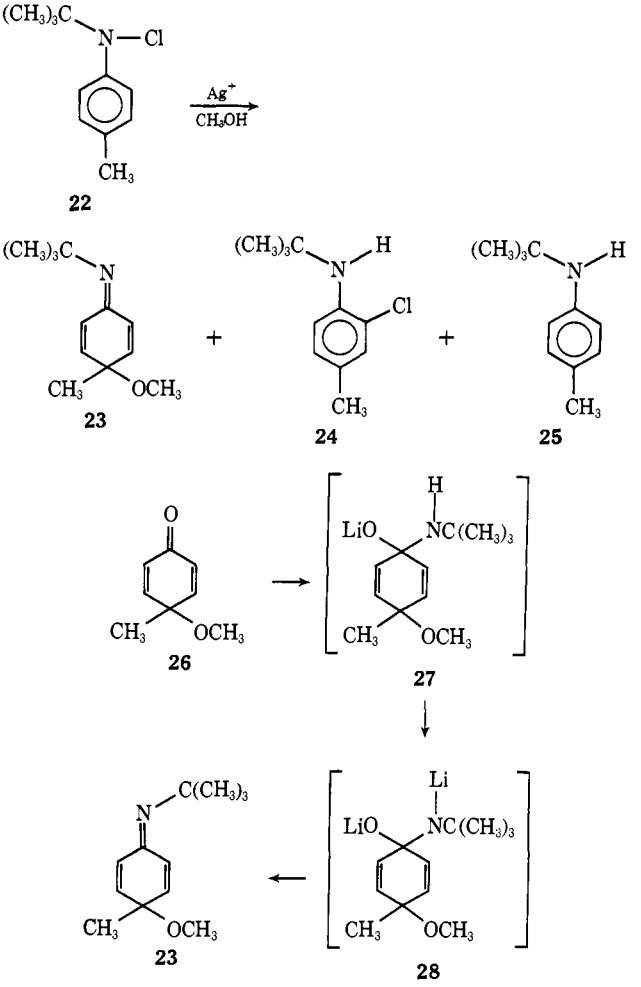
Starting material	Silver salt	Temp, °C	Anisole[a]	Yield, %
N-tert-Butyl-*N*-chloroaniline (**5**)	$AgOCCF_3$ or $AgClO_4$	−8	 **6**	39
N-Methyl-*N*-chloroaniline (**10**)	$AgOCCF_3$	−20	 **14**	30
N-tert-Butyl-*N*-chloro-*o*-toluidine (**11**)	$AgOCCF_3$	−78	 **15**	40
N-Methyl-*N*-chloro-*o*-aminobiphenyl (**12**)	$AgOCCF_3$	−78	 **16**	51
2,6,*N*-Trimethyl-*N*-chloroaniline (**13**)	$AgOCCF_3$	−78	 **17**	77

[a] In addition to the anisoles, smaller amounts of other products were formed. For the details concerning these other products see the Experimental Section.



the para position of the starting *N*-chloroaniline, it seemed reasonable that the reaction might be able to be stopped at this stage. Isolation of a 2,5-cyclohexadienone derivative would then provide supporting evidence for the proposed mechanism. With these concepts in mind, we explored the silver ion promoted methanolysis of a series of para-substituted *N*-chloroanilines.

When *N-tert*-butyl-*N*-chloro-*p*-toluidine (**22**) was treated with silver trifluoroacetate in methanol at 0°, an immediate precipitation of silver chloride was observed. The product mixture obtained from this reaction yielded 70% of **23**, 17% of **24**, and 2% of **25**. The structure of **23** was established on the basis of its spectral properties (see Experimental Section) and through comparison with an authentic sample. In an independent synthesis, **23** was prepared in 52% yield from 4-methoxy-4-methylcyclohexa-2,5-dienone[13] (**26**), through the initial addition of lithio-*tert*-butylamine in ether to **26** to yield **27**, followed by the addition of 1 equiv of methyllithium to yield **28**.[14] When **28** was heated, loss



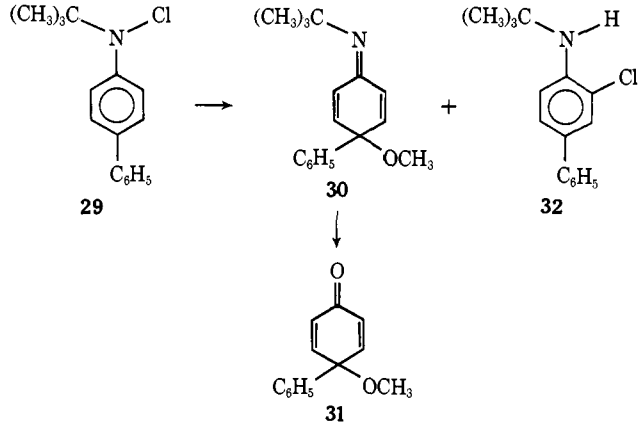
of lithium oxide occurred and **23** was produced.[15]

(13) E. Hecker and R. Lattrell, *Justus Liebigs Ann. Chem.*, **662**, 48 (1963).

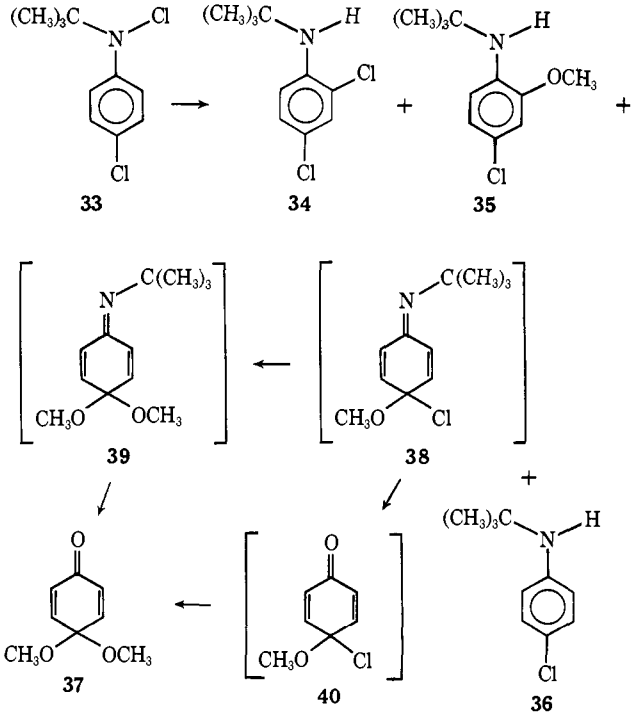
(14) We wish to thank Dr. R. Steppel for his helpful suggestions in connection with the development of this synthetic route.

(15) The ease of this synthetic procedure indicated that it might constitute a superior method for the preparation of elusive imines.

The formation of 2,5-cyclohexadienone imine derivatives was not limited to the silver ion promoted methanolysis of **22**. *N-tert*-Butyl-*N*-chloro-*p*-aminobiphenyl (**29**) reacted with silver ion in methanol to give **30** which was hydrolyzed directly to **31** in 62% yield based on **29**. In addition, 5% of **32** was formed.

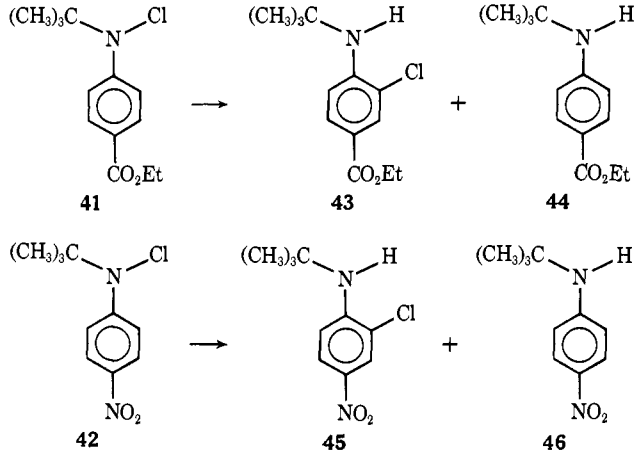


When chlorine was present in the para position, as in *N-tert*-butyl-*N*,*p*-dichloroaniline (**33**), a more complex reaction mixture was formed in the presence of methanolic silver trifluoroacetate. Under these conditions, **33** gave **34** (25%), **35** (26%), **36** (12%), and **37** (10%). 4,4-Dimethoxy-2,5-cyclohexadienone (**37**) was identified through spectral comparison with published data.[16] It would appear that **37** was derived from **38** under the reaction conditions. It was not evident whether **37** was formed *via* initial solvolysis of **38** to yield **39** followed by hydrolysis to give **37**, or whether **38** was first hydrolyzed to **40** which then was solvolyzed to **37** in the methanolic silver trifluoroacetate.



The formation of **23** from **22**, **31** from **29**, and **37** from **33** supported the mechanism proposed for the formation of anisidines from *N*-chloroanilines which are not substituted in the para position. In addition to lending credence to the mechanistic postulate, these reactions provided a simple route to a variety of derivatives of 2,5-cyclohexadienone. As recently discussed,[17] 2,5-cyclohexadienones are potentially valuable intermediates in the synthesis of a wide variety of complex molecules. Unfortunately, up to this time their use as synthetic intermediates has been limited by the problems involved in their synthesis. We hope that the versatility of our synthetic route to 2,5-cyclohexadienone derivatives will help to remedy this problem.

The decreased yield of the 2,5-cyclohexadienone derivative in the solvolysis of **33**, relative to the yield for the *p*-phenyl and *p*-methyl cases, indicated that the slightly electron-withdrawing *p*-chloro substituent of **33** might be inhibiting charge delocalization to the para position. In order to test this hypothesis, we studied the solvolysis of ethyl *p*-(*N*-chloro-*N-tert*-butylamino)-benzoate (**41**) and *p*-(*N*-chloro-*N-tert*-butylamino)nitrobenzene (**42**). Solvolysis of **41** in methanolic silver trifluoroacetate gave 58% of **43** and 26% of **44**. Similarly, **42** yielded 65% of **45** and 25% of **46**. In neither



case was any product derived from a 2,5-cyclohexadienone detected. In addition, no incorporation of a methoxyl group could be detected in the silver ion promoted methanolysis of either **41** or **42**.

From the data presented above it is obvious that *N*-chloroanilines with electron-donating substituents undergo silver ion promoted solvolysis with nucleophilic attack of solvent as the major reaction pathway. As the substituents on the aromatic ring become increasingly electron withdrawing, incorporation of solvent in a nucleophilic reaction decreases up to the point where there is no solvent incorporation for *p*-carboethoxy and *p*-nitro-substituted *N*-chloroanilines. Table III lists the percentages of methoxylated products obtained in the silver ion promoted methanolysis of para-substituted *N*-chloroanilines. The total amount of methoxylated product includes the amount of *o*-anisidines, *p*-anisidines, and 2,5-cyclohexadienones. A reasonable correlation can be noted between the electron-withdrawing power of the para substituent and the percentage of solvent incorporation. The complete lack of solvent incorporation in the silver ion promoted solvolysis of the *p*-carboethoxy- and *p*-nitro-*N-tert*-butyl-*N*-chloroanilines seemed to be somewhat anomalous.

(16) W. Duerckheimer and L. Cohen, *Biochemistry*, 3, 1948 (1964).

(17) E. J. Corey, S. Boreze, and G. Klotmann, *J. Amer. Chem. Soc.*, 91, 4782 (1969).

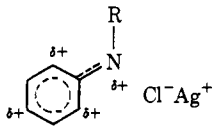
Table III. Percentage of Products Resulting from Solvent Incorporation in the Silver Ion Promoted Methanolysis of *N*-*tert*-Butyl-*N*-chloroanilines

Substituent in the para position	Yield of products due to solvent addition, %
CH_3	70
C_6H_5	62
H	45
Cl	36
CO_2Et	0[a]
NO_2	0[a]

[a] Within the limits of detection by vpc analysis, no methoxylated products could be detected.

Although silver ion was qualitatively accelerating the reaction, silver chloride formation represented a minor portion of the reaction. Even in the case of *N*-*tert*-butyl-*N*-chloro-*p*-toluidine (**22**), a significant amount of the reaction (17%) proceeded by a path which allowed chloride recapture by the aromatic nucleus.

We feel that the formation of the ring chlorinated products in the silver ion promoted solvolysis of *N*-chloroanilines also proceeds through a mechanistic route which involves an anilenium ion. The incorporation of chloride is consistent with the silver ion catalyzed formation of a "tight ion pair" which involves the anilenium ion, chloride ion, and silver ion as represented by **47**.[18] As substituents on the ring become more



47

electron withdrawing, the stability of the anilenium ion decreases. This would be expected to result in the formation of a tighter ion complex. In the extreme cases of *p*-carboethoxy- and *p*-nitro-*N*-chloroanilines it would appear that collapse of the very tight ion complex to ring chlorinated products occurs to the complete exclusion of nucleophilic attack by solvent.

In summary we have developed useful synthetic methods for the preparation of anisoles and derivatives of 2,5-cyclohexadienone. A mechanism which involves the initial formation of a highly delocalized phenylnitrenium ion is supported for these reactions. In addition it is suggested that the rearrangement of *N*-chloroanilines to ring chlorinated products involves the intermediacy of a phenylnitrenium ion.[19]

Experimental Section

Elemental analyses were performed by the Scandinavian Microanalytical Laboratory, Herlev, Denmark. Melting and boiling points are uncorrected. Infrared spectra were taken on a Perkin-Elmer Model 137 Infracord as neat liquids, solutions in carbon tetrachloride, or powdered solids in potassium bromide disks. Nuclear magnetic resonance spectra were obtained on Varian Associates A-60-A and HA-100 spectrometers and reported in τ units relative to tetramethylsilane (τ = 10.00) as the internal standard.

N-*tert*-**Butylaniline.** This compound was prepared by the method of Bell and Knowles.[11]

N-*tert*-**Butyl-*p*-toluidine.** A mixture of 50 g (0.348 mol) of *p*-toluidine hydrochloride and 100 ml of *tert*-butyl alcohol was sealed in a steel bomb and heated at 155° for 24 hr. The bomb was then cooled in a Dry Ice–2-propanol bath and opened. The contents were dissolved in 300 ml of water, made basic with aqueous ammonium hydroxide solution, and extracted with three 200-ml portions of ether. The combined ethereal extracts were dried over anhydrous magnesium sulfate, filtered, and concentrated on the rotary evaporator to leave a red oil. The oil was then added to a mixture of 20 g of acetic anhydride in 300 ml of water and stirred for 3 hr. Excess sodium bicarbonate was slowly added and the mixture steam distilled until the distillate was neutral to litmus paper. The distillate was extracted with three 100-ml portions of ether. The combined ethereal extracts were dried over anhydrous magnesium sulfate, filtered, and concentrated on the rotary evaporator to leave a dark oil. The oil was fractionally distilled to give 35.0 g (62%) of pure *N*-*tert*-butyl-*p*-toluidine: bp 64° (0.35 mm); n^{25}D 1.5164; ir (neat) 2.82, 6.14, 6.49, and 12.35 μ; nmr (CCl_4) τ 8.73 (9 H, s), 7.79 (3 H, s), 3.35 (4 H, q). The compound was analyzed as the hydrochloride, mp 261–263°.

Anal. Calcd for $C_{11}H_{18}NCl$: C, 66.14; H, 9.08; N, 7.01; Cl, 17.75. Found: C, 66.47; H, 9.12; N, 6.95; Cl, 17.54.

N-*tert*-**Butyl-*p*-anisidine (6).** The procedure was identical with that used in the preparation of *N*-*tert*-butyl-*p*-toluidine. In this manner **6** was synthesized from *p*-anisidine in 54% yield: bp 54–57° (0.04 mm); n^{25}D 1.5225; ir (neat) 3.03, 6.33, 7.75, and 9.26 μ; nmr (CCl_4) τ 8.87 (9 H, s), 6.45 (3 H, s), 6.99 (1 H, s), 3.33 (4 H, m).

Anal. Calcd for $C_{11}H_{17}NO$: C, 73.70; H, 9.56; N, 7.81. Found: C, 73.79; H, 9.59; N, 7.79.

N-*tert*-**Butyl-*o*-anisidine (7).** The procedure was identical with that used in the preparation of *N*-*tert*-butyl-*p*-anisidine. In this manner **7** was synthesized in 42% yield from *o*-anisidine: bp 48–49° (0.06 mm); $n^{25.4}$D 1.5273; ir (neat) 2.90, 6.21, 8.13, 8.93, and 13.72 μ; nmr (CCl_4) τ 8.67 (9 H, s), 6.22 (3 H, s), 6.00 (1 H, s), 3.33 (4 H, m).

Anal. Calcd for $C_{11}H_{17}NO$: C, 73.70; H, 9.56; N, 7.81. Found: C, 73.69; H, 9.63; N, 7.93.

N-*tert*-**Butyl-*o*-toluidine.** A mixture of 33.4 g (0.23 mol) of *o*-toluidine hydrochloride and 250 ml of *tert*-butyl alcohol was sealed in a steel bomb and heated to 150° for 8 hr. The bomb was cooled and opened and the reaction mixture was added to 500 ml of water, made basic with ammonium hydroxide solution, and extracted with three 200-ml portions of ether. The combined ethereal extracts were dried over anhydrous magnesium sulfate and filtered, and the solvent was removed *in vacuo* to leave a dark oil. The oil was chromatographed on 250 g of Activity I basic alumina (eluted with hexane) to separate the product from starting material. Distillation of the purified product gave 5.2 g (14%): bp 50–51° (0.37 mm); $n^{25.9}$D 1.5178; ir (neat) 2.90, 6.25, 6.75, 8.15, and 13.50 μ; nmr (CCl_4) τ 8.62 (9 H, s), 7.92 (3 H, s), 6.75 (1 H, s), 3.10 (4 H, m).

Anal. Calcd for $C_{11}H_{17}N$: C, 80.92; H, 10.50; N, 8.58. Found: C, 80.97; H, 10.41; N, 8.60.

N-*tert*-**Butyl-*p*-chloroaniline (9).**[7] The procedure was identical with that used for the preparation of *N*-*tert*-butyl-*p*-toluidine. In this manner the desired compound was synthesized from *p*-chloroaniline in 54% yield: bp 67° (0.6 mm); n^{25}D 1.5420 (lit.[7] n^{24}D 1.5416).

p-(*N*-*tert*-**Butylamino)biphenyl.** A mixture of 16 g of *p*-aminobiphenyl hydrochloride and 80 ml of *tert*-butyl alcohol was placed in a steel bomb and heated at 155° for 12 hr. The bomb was then cooled in a Dry Ice–2-propanol bath and opened. The contents were added to 250 ml of water, made basic with ammonium hydroxide solution, and extracted with three 100-ml portions of ether. The ethereal extracts were combined, dried over anhydrous magnesium sulfate, filtered, and concentrated on the rotary evaporator to give a dark oil. The oil partially crystallized on standing, but recrystallizing from hexane failed to purify the reaction mixture. Chromatography on Activity I basic alumina (hexane–ether solvent) gave 10.7 g (61%) of pure *p*-(*N*-*tert*-butylamino)biphenyl: mp 63–64.5°; ir (KBr) 6.33, 12.08, 13.10, and 14.39 μ; nmr (CCl_4) τ 8.64 (9 H, s), 6.68 (1 H, s), 3.32 (2 H, d), 2.60 (7 H, m).

Anal. Calcd for $C_{16}H_{19}N$: C, 85.28; H, 8.50; N, 6.22. Found: C, 85.47; H, 8.48; N, 6.25.

Ethyl *p*-(*N*-*tert*-Butylamino)benzoate. A mixture of 24 g of benzocaine hydrochloride and 80 ml of *tert*-butyl alcohol was sealed in a steel bomb and heated to 125–140° for 16 hr. The bomb was cooled in a Dry Ice–2-propanol bath and opened. The contents were added to 200 ml of water, made basic with ammonium hydroxide solution, and extracted with three 200-ml portions of ether. The combined ethereal extracts were dried over anhydrous magne-

(18) Ample precedent exists for the formation of tight ion situations of this type in the rearrangement of certain *N*-chloroazabicyclic molecules where silver ion greatly increases the rates of rearrangement but fails to decrease the amount of chloride recapture by the positively charged bicyclic skeleton. For details see P. G. Gassman and R. L. Cryberg, *ibid.*, 91, 2047 (1969).

(19) For confirmation of this hypothesis see ref 10.

sium sulfate and filtered, and the solvents removed *in vacuo* to leave a viscous yellow oil. The oil was chromatographed on Activity II basic alumina (hexane–ether solvent) to give the desired product as a white crystalline solid. Recrystallization from hexane gave 9.02 g (34%) of the amino ester: mp 70–72°; ir (KBr) 5.88, 5.92, 11.87, 12.93, and 14.21 μ; nmr (CCl_4) τ 8.64 (12 H, m), 5.70 (2 H, q), 2.78 (4 H, q).

Anal. Calcd for $C_{13}H_{19}NO_2$: C, 70.55; H, 8.65; N, 6.33. Found: C, 70.65; H, 8.79; N, 6.41.

***p*-(*N*-*tert*-Butylamino)nitrobenzene.** This compound was prepared according to the method of Suhr.[12]

2,6,*N*-Trimethylaniline. A solution of 15.0 g (0.124 mol) of 2,6-dimethylaniline in 50 ml of ethyl formate was refluxed for 4 days. The excess ethyl formate was then removed on the rotary evaporator to leave a damp solid. The wet solid was washed with two 50-ml portions of ether to remove unreacted 2,6-dimethylaniline. After drying *in vacuo* the crude formamide weighed 10.0 g (64%). To a refluxing solution of 4.0 g of lithium aluminum hydride in 500 ml of dry tetrahydrofuran was added 10.0 g of the crude formamide in small portions. After the addition was complete, the reaction was refluxed for 2 days. The excess hydride was destroyed by dropwise addition of 16 ml of water followed by a 2-hr reflux. The salts were removed by filtration and the solvents removed *in vacuo* to give the crude secondary amine. Short-path distillation gave 8.3 g of the desired product, bp 43–44° (0.5 mm), for a 92% yield from the formamide.

***o*-(*N*-Methylamino)biphenyl.** This compound was prepared according to the procedure of Dyall,[20] bp 107° (0.1 mm) [lit.[20] bp 130° (1.5 mm)].

Chlorination and Solvolysis of *N*-*tert*-Butylaniline. A solution of 2.1 g of *N*-*tert*-butylaniline in 250 ml of carbon tetrachloride was vigorously stirred for 1 hr with 250 ml of 6% sodium hypochlorite solution at −8° under nitrogen by means of a Vibro-mixer mechanical stirrer. The organic layer was then separated and dried over anhydrous magnesium sulfate in the cold. The cold mixture was filtered into a solution of 9.3 g of silver trifluoroacetate in 500 ml of methanol at −8°. Silver chloride began to precipitate. After the reaction mixture was stirred in the cold for 18 hr, it was allowed to come to room temperature and excess lithium chloride was added to precipitate the excess silver ion. The silver chloride was removed by filtration and the solvents were evaporated *in vacuo* to leave a red oil. The residue was added to 100 ml of 5% sodium hydroxide solution and the resulting mixture was extracted with three 50-ml portions of pentane. The combined pentane extracts were dried over anhydrous magnesium sulfate, filtered, and concentrated on the rotary evaporator to leave a red oil. Distillation gave 1.91 g of a clear oil, bp 60–70° (0.75 mm). Gas chromatography on a 3% Amine 220 on Diaport S column indicated the presence of five products in the reaction mixture. Small amounts of the five products were isolated in pure form by preparative gas chromatography on the same column. The first component was *N*-*tert*-butylaniline. The second component was *N*-*tert*-butyl-*o*-chloroaniline (**8**), which was identified through comparison of physical properties with published data.[7] The third component was *N*-*tert*-butyl-*o*-anisidine (**7**): bp 48–49° (0.06 mm); $n^{25.4}$D 1.5273; ir (neat) 6.20, 6.54, 7.52, and 13.72 μ; nmr (CCl_4) τ 8.67 (9 H, s), 6.23 (3 H, s), 3.30 (4 H, m). The fourth compound was *N*-*tert*-butyl-*p*-anisidine (**6**): bp 54–57° (0.04 mm); n^{25}D 1.5225; ir (neat) 6.62, 8.13, 9.52, and 12.20 μ; nmr (CCl_4) τ 8.88 (9 H, s), 6.46 (3 H, s), 3.31 (4 H, s). The fifth compound was *N*-*tert*-butyl-*p*-chloroaniline (**9**) which was identical with an authentic sample.[7]

The reaction was repeated and analyzed on a 3% Amine 220 on Diaport S column using naphthalene as an internal standard which showed 6% of *N*-*tert*-butylaniline, 39% of **6**, 28% of **8**, 6% of **7**, and 6% of **9**.

Chlorination and Solvolysis of *N*-Methylaniline. A solution of 1.5 g of *N*-methylaniline in 250 ml of carbon tetrachloride and 250 ml of a 6% sodium hypochlorite solution was vigorously stirred with a Vibro-mixer mechanical stirrer for 45 min at −6° under nitrogen. The organic layer was separated, dried over anhydrous magnesium sulfate, filtered, and added to a solution of 2.0 g of silver trifluoroacetate in 500 ml of methanol at −20°. After the mixture was stirred for 30 min, lithium chloride was added to precipitate the excess silver ion. The silver chloride was removed by filtration and the solvents were evaporated *in vacuo*. The residue was taken up in 100 ml of 5% sodium hydroxide solution and extracted with three 50-ml portions of ether. The combined ethereal extracts were dried over anhydrous magnesium sulfate, filtered, and concentrated on the rotary evaporator to leave a dark oil. The oil was separated into five components by preparative gas chromatography on a 3% Amine 220 on 80–100 Diaport S column to give *N*-methylaniline, *N*-methyl-*p*-anisidine (**14**), *N*-methyl-*o*-anisidine, *N*-methyl-*o*-chloroaniline, and *N*-methyl-*p*-chloroaniline. All of the compounds were identified by comparison of their ir, nmr, and refractive indices with those of authentic samples. The reaction was repeated and analysis *via* gas chromatography on the same type of column (*vs.* 2,6-dichloroaniline as an internal standard) yielded 30% of **14**, 1% of *N*-methyl-*o*-anisidine, 6% of *N*-methyl-*p*-chloroaniline, 9% of *N*-methyl-*o*-chloroaniline, and 5% of *N*-methylaniline.

Chlorination and Solvolysis of *N*-*tert*-Butyl-*o*-toluidine. To a solution of 0.5 g (3.07 mmol) of *N*-*tert*-butyl-*o*-toluidine in 250 ml of pentane at −78° was added a solution of 0.367 g (3.38 mmol) of *tert*-butyl hypochlorite in 20 ml of pentane. After the reaction mixture was stirred for 2 hr at −78°, it was added to a solution of 2.04 g (9.31 mmol) of silver trifluoroacetate in 300 ml of methanol at −78°. The solution was then allowed to slowly warm to room temperature. After the solution was stirred for 1 hr at room temperature, excess lithium chloride was added and the silver chloride was removed by filtration to leave a yellow solution. The solvents were evaporated to give a yellow oil which was taken up in 50 ml of water, made basic with sodium hydroxide pellets, and extracted with three 75-ml portions of ether. The combined ethereal extracts were dried over anhydrous magnesium sulfate and filtered, and the solvents were evaporated to yield an oil. The oil was chromatographed on Activity I basic alumina (Skelly B–ether) to give 50 mg (10%) of *N*-*tert*-butyl-*o*-toluidine and 224 mg (38%) of *N*-*tert*-butyl-4-methoxy-2-methylaniline (**15**): $n^{24.8}$D 1.5192; ir (neat) 3.03, 6.67, 8.12, 9.48, and 12.32 μ; nmr (CCl_4) τ 7.90 (3 H, s), 7.20 (1 H, s), 6.34 (3 H, s), 3.43 (3 H, m).

Anal. Exact mass molecular weight, Calcd for $C_{12}H_{19}NO$: 193.14665. Found: 193.14678.

Chlorination and Solvolysis of *o*-(*N*-Methylamino)biphenyl. To a solution of 0.510 g of *o*-(*N*-methylamino)biphenyl in 40 ml of methylene chloride at −78° was added a solution of 0.325 g of *tert*-butyl hypochlorite in 10 ml of methylene chloride. After the solution was stirred at −78° for 15 min, a solution of 0.606 g of silver trifluoroacetate in 75 ml of methanol was added dropwise over a 30-min period. The mixture was allowed to stir at −78° for 1 hr and then gradually allowed to warm to room temperature to give a blue solution with much silver chloride precipitation. The salts were removed by filtration and the solvent was evaporated *in vacuo* to give a dark oil. The oil was taken up in 50 ml of 10% sodium hydroxide solution and extracted with three 75-ml portions of ether. The combined ethereal extracts were dried over anhydrous magnesium sulfate and filtered, and the solvents removed on the rotary evaporator to leave a red oil. Chromatography on Activity I basic alumina (ether–hexane solvent) separated the oil into three components. The first component was *o*-(*N*-methylamino)biphenyl. The second compound eluted was 3-chloro-2-(*N*-methylamino)biphenyl: $n^{23.8}$D 1.6225; ir (neat) 6.62, 6.76, 7.07, 13.10, and 14.20 μ; nmr (CCl_4) τ 7.58 (3 H, s), 6.10 (1 H, s), 3.15 (3 H, m), 2.60 (5 H, m).

Anal. Calcd for $C_{13}H_{12}NCl$: C, 71.87; H, 5.57; N, 6.45; Cl, 16.11. Found: C, 71.59; H, 5.75; N, 6.45; Cl, 16.54.

The third component eluted was 5-methoxy-2-(*N*-methylamino)-biphenyl (**16**): ir (neat) 3.03, 6.62, 8.20, 9.56, and 14.17 μ; nmr (CCl_4) τ 7.28 (3 H, s), 6.60 (1 H, s), 6.31 (3 H, s), 3.38 (3 H, m), 2.67 (5 H, m).

Anal. Calcd for $C_{14}H_{15}NO$: C, 78.84; H, 7.07; N, 6.57. Found: C, 78.50; H, 7.00; N, 6.43.

The reaction was repeated and analysis *via* vapor-phase chromatography on a 20% 4:1 Apiezon L–KOH on 80–100 Firebrick column (*vs.* *p*-(*N*-*tert*-butylamino)biphenyl as an internal standard) yielded 51% of **16**, 4% of 3-chloro-2-(*N*-methylamino)biphenyl, and 7% of *o*-(*N*-methylamino)biphenyl.

Chlorination and Solvolysis of 2,6,*N*-Trimethylaniline. To a solution of 1.0 g of 2,6,*N*-trimethylaniline in 100 ml of methanol at −78° was added a solution of 0.884 g of *tert*-butyl hypochlorite in 20 ml of methanol. After the mixture was stirred for 20 min at −78°, a solution of 1.64 g of silver trifluoroacetate in 20 ml of methanol was added dropwise. Silver chloride immediately precipitated. The mixture was stirred for an additional 40 min at −78° and then allowed to come to room temperature. The silver chloride was removed by filtration and the solvents were evaporated *in vacuo* to leave a blue oil. The oil was taken up in 50 ml of water, made basic with sodium hydroxide pellets, and extracted with three 100-ml portions of ether. The combined ethereal extracts were dried over

(20) L. K. Dyall, *Aust. J. Chem.*, **20**, 93 (1967).

anhydrous magnesium sulfate and filtered, and the solvent was evaporated to leave a red oil. The oil was separated into two components by chromatography on 150 g of Activity I basic alumina (hexane–ether solvent), although some overlap of the two bands occurred. The first component eluted was 0.100 g (8%) of 4-chloro-2,6,*N*-trimethylaniline: $n^{28.6}$D 1.5503; ir (neat) 6.75, 8.13, 11.32, and 11.57 μ; nmr (CCl_4) τ 7.80 (6 H, s), 7.30 (3 H, s), 7.26 (1 H, s), 3.13 (2 H, s). The compound was analyzed as the hydrochloride, mp 225° dec.

Anal. Calcd for $C_9H_{13}NCl_2$: C, 52.67; H, 6.39; N, 6.83; Cl, 34.11. Found: C, 52.73; H, 6.40; N, 6.88; Cl, 33.84.

The second component eluted was 2,6,*N*,trimethyl-4-anisidine (**17**): $n^{28.6}$D 1.5342; ir (neat) 6.62, 6.76, 8.66, and 9.34 μ; nmr (CCl_4) τ 7.79 (6 H, s), 7.38 (3 H, s), 7.53 (1 H, s), 6.35 (3 H, s), 3.58 (2 H, s). The compound was analyzed as the hydrochloride, mp 260° dec.

Anal. Calcd for $C_{10}H_{16}NOCl$: C, 59.67; H, 8.02; N, 6.96; Cl, 17.37. Found: C, 59.39; H, 8.09; N, 6.98; Cl, 17.88.

The reaction was repeated and the product mixture was analyzed on a 10% Carbowax 20M–KOH on 60–80 Chromosorb W column (*vs. o*-toluidine as an internal standard) to yield 77% of **17**, 17% of 4-chloro-2,6,*N*-trimethylaniline, and 2% of 2,6,*N*-trimethylaniline.

Chlorination and Solvolysis of *N*-*tert*-Butyl-*p*-toluidine. A mixture of 2.0 g of the amine in 50 ml of carbon tetrachloride and 11.3 g of solid calcium hypochlorite was vigorously stirred at 0–5° for 1 hr. The salts were then removed by filtration to leave a clear solution of the *N*-chloro compound **22**. This solution was added to a solution of 8.15 g of silver trifluoroacetate in 100 ml of methanol at 0–5°. Silver chloride immediately precipitated and the mixture was allowed to stir for 3 hr at 0–5°. Silver chloride was removed by filtration and the solvents were removed on the rotary evaporator to leave a viscous residue. The residue was added to 50 ml of water, made basic with ammonium hydroxide solution, and extracted with three 50-ml portions of ether. The combined ethereal extracts were dried over anhydrous magnesium sulfate, filtered, and concentrated *in vacuo* to leave a viscous oil. The components of the oil were separated *via* preparative vapor-phase chromatography on a 20% 4:1 Apiezon L–KOH on 60–80 Firebrick column. The first component eluted was 4-methyl-4-methoxy-2,5-cyclohexadienone *N*-*tert*-butylimine (**23**): mp 56–58°; ir (CCl_4) 6.13, 6.25, 7.30, 8.20, and 9.17 μ; nmr (CCl_4) τ 8.71 (3 H, s), 8.68 (9 H, s), 6.96 (3 H, s), 4.01 (4 H, m).

Anal. Calcd for $C_{12}H_{19}NO$: C, 74.57; H, 9.91; N, 7.25. Found: C, 74.44; H, 10.00; N, 7.23.

The second component eluted was *N*-*tert*-butyl-*p*-toluidine (**25**). The third component eluted was *N*-*tert*-butyl-*o*-chloro-*p*-toluidine (**24**): n^{25}D 1.5278; ir (neat) 6.13, 6.50, 8.16, and 12.40 μ; nmr (CCl_4) τ 8.64 (9 H, s), 7.77 (3 H, s), 3.14 (3 H, m).

Anal. Calcd for $C_{11}H_{16}NCl$: C, 66.82; H, 8.16; N, 7.09; Cl, 17.93. Found: C, 67.06; H, 8.10; N, 6.98; Cl, 18.02.

Vpc analysis of a repeat reaction (*vs.* **9** as an internal standard) yielded 70% of **23**, 17% of **24**, and 2% of **25**.

4-Methyl-4-methoxy-2,5-cyclohexadienone *N*-*tert*-Butylimine (23). A solution of lithio-*tert*-butylamine was prepared by the addition of 0.264 g of *tert*-butylamine in 10 ml of dry ether to 2.24 ml of a 5.02% solution of methyllithium in ether at room temperature. To this solution was then added 0.500 g of 4-methyl-4-methoxy-2,5-cyclohexadienone (**26**)[13] in 25 ml of dry ether. After the mixture was stirred at room temperature for 3 hr, 1 equiv of methyllithium was added followed by 12 hr at reflux. The reaction was quenched by the addition of 10 ml of water, followed by extraction with three 40-ml portions of ether. The combined ethereal extracts were dried over anhydrous magnesium sulfate and filtered, and the solvent was evaporated to leave an oil. The desired product was isolated by preparative vapor-phase chromatography on a 20% 4:1 Apiezon L–KOH on 60–80 Firebrick column to give 350 mg (52%) of **23**. It was shown to be identical with the product from the solvolysis of **22** by ir, nmr, and mixture melting point (56–58°).

Chlorination and Solvolysis of *p*-(*N*-*tert*-Butylamino)biphenyl. A mixture of 1.5 g of *p*-(*N*-*tert*-butylamino)biphenyl in 50 ml of pentane and 10.00 g of powdered calcium hypochlorite was stirred at 0–5° for 2 hr. The salts were then removed by filtration and the solution was concentrated at 0–5° on the rotary evaporator to 10 ml at which time the chloramine precipitated. The solid was collected by filtration and air-dried to give 1.5 g of **29**, mp 86–88° dec. Pure **29** was not analyzed since it rearranged readily to 3-chloro-4-(*N*-*tert*-butylamino)biphenyl (**32**), even on storage in the refrigerator.

To a solution of 2.94 g of silver trifluoroacetate in 50 ml of methanol at room temperature was added 1.00 g of **29**. Silver chloride immediately precipitated. After the reaction mixture was stirred overnight, 2.0 g of sodium chloride was added. The silver chloride was removed by filtration and the solvents were evaporated *in vacuo*. The residue was taken up in 50 ml of 5% sodium hydroxide solution and the mixture was extracted with three 100-ml portions of ether. The ethereal extracts were combined, dried over anhydrous magnesium sulfate, and filtered, and the solvent was evaporated to leave a red oil. Chromatography on 60 g of Activity I basic alumina (hexane–ether solvent) gave two compounds.

First eluted was 50 mg (5%) of **32**: $n^{25.4}$D 1.6132; ir (neat) 3.03, 6.23, 8.20, 13.15, and 14.32 μ; nmr (CCl_4) τ 8.57 (9 H, s), 2.60 (8 H, m).

Anal. Calcd for $C_{16}H_{18}NCl$: C, 73.97; H, 6.98; N, 5.39; Cl, 13.65. Found: C, 74.03; H, 7.08; N, 5.41; Cl, 13.60.

The second product eluted was 495 mg (62%) of 4-methoxy-4-phenyl-2,5-cyclohexadienone (**31**): mp 91–93°; ir (KBr) 5.92, 5.98, 8.33, 11.59, 13.15, and 14.21 μ; nmr (CCl_4) τ 6.56 (3 H, s), 3.48 (4 H, q), 2.61 (5 H, m).

Anal. Calcd for $C_{13}H_{12}O_2$: C, 77.98; H, 6.04. Found: C, 78.07; H, 6.03.

Chlorination and Solvolysis of *N*-*tert*-Butyl-*p*-chloroaniline. A mixture of 2.0 g of *N*-*tert*-butyl-*p*-chloroaniline in 50 ml of carbon tetrachloride and 14.3 g of finely powdered calcium hypochlorite was stirred at room temperature for 2 hr. The mixture was then filtered and the chloramine solution was added to a solution of 3.02 g of silver trifluoroacetate in 100 ml of methanol at 0–5°. After the mixture was stirred for 20 min, excess lithium chloride was added. The silver chloride was removed by filtration and the solvents were evaporated *in vacuo* to leave a red oil. The oil was taken up in 50 ml of water, made basic with ammonium hydroxide solution, and extracted with three 50-ml portions of ether. The combined ethereal extracts were dried over anhydrous magnesium sulfate and filtered, and the solvent was removed on the rotary evaporator to leave a red oil. The oil was separated into four components *via* preparative gas chromatography on a 20% 4:1 Apiezon L–KOH on 60–80 Firebrick column. The first compound eluted was 4,4-dimethoxy-2,5-cyclohexadienone (**37**), which was identified by comparison of ir, uv, and nmr spectra with published data.[16] The second component to be eluted was *N*-*tert*-butyl-*p*-chloro-*o*-anisidine (**35**): n^{25}D 1.5425; ir (neat) 6.24, 6.62, 8.13, 9.70, and 11.50 μ; nmr (CCl_4) τ 8.69 (9 H, s), 6.28 (3 H, s), 7.10 (3 H, m).

Anal. Calcd for $C_{11}H_{16}NOCl$: C, 61.82; H, 7.55; N, 6.55; Cl, 16.59. Found: C, 61.95; H, 7.49; N, 6.47; Cl, 17.03.

The third product observed was *N*-*tert*-butyl-*o*,*p*-dichloroaniline (**34**): n^{25}D 1.5477; ir (neat) 6.21, 6.62, 8.20, 11.51, 12.41, and 13.01 μ; nmr (CCl_4) τ 8.63 (9 H, s), 7.13 (3 H, m).

Anal. Calcd for $C_{10}H_{13}NCl_2$: C, 55.06; H, 6.01; N, 6.42; Cl, 32.51. Found: C, 55.29; H, 6.00; N, 6.42; Cl, 32.43.

The fourth component eluted was *N*-*tert*-butyl-*p*-chloroaniline.

The reaction was repeated and analyzed on a 10% Carbowax 20M–KOH on 60–80 Chromosorb W column (*vs.* naphthalene as an internal standard) to yield 25% of **34**, 26% of **35**, 10% of **37**, and 12% of *N*-*tert*-butyl-*p*-chloroaniline.

Chlorination and Solvolysis of Ethyl *p*-(*N*-*tert*-Butylamino)benzoate. To a solution of 1.0 g of ethyl *p*-(*N*-*tert*-butylamino)benzoate in 50 ml of pentane was added 10.0 g of finely powdered calcium hypochlorite. Vigorous stirring was initiated and continued at room temperature for 4 hr. The salts were removed by filtration and the solvent was evaporated *in vacuo*, while keeping the flask cold, to give the neat chloramine **41** as a pale yellow oil. Infrared analysis showed the complete absence of the N–H band of the starting amine. The chloramine was then added to a solution of 3.02 g of silver trifluoroacetate in 50 ml of methanol. Silver chloride slowly precipitated. Stirring was continued for 2 hr at which time an iodometric test for active chlorine was negative. Excess silver ion was then precipitated with lithium chloride and the silver chloride was removed by filtration. The solvents were removed on the rotary evaporator and the residue was taken up in 50 ml of 5% sodium bicarbonate solution and extracted with three 50-ml portions of ether. The combined ethereal extracts were dried over anhydrous magnesium sulfate and filtered, and the solvent was evaporated to leave a yellow residue. The residue was separated into its components by preparative vapor-phase chromatography on a 20% 4:1 Apiezon L–KOH on 60–80 Firebrick column. The first component was recrystallized from hexane to give ethyl 3-chloro-4-(*N*-*tert*-butylamino)benzoate (**43**): mp 61–63°; ir (KBr) 2.96, 5.84, 7.76, 13.01, and 13.80 μ; nmr (CCl_4) τ 8.53 (9 H, s), 8.65 (3 H, t), 5.71 (2 H, q), 3.13 (1 H, d), 3.10 (2 H, m).

Anal. Calcd for $C_{13}H_{18}NO_2Cl$: C, 61.05; H, 7.09; N, 5.48; Cl, 13.87. Found: C, 61.19; H, 7.12; N, 5.48; Cl, 13.47.

The second component was the starting amine **44**.

The reaction was repeated and analysis *via* gas chromatography on the same type of column (*vs.* ethyl *p*-aminobenzoate as the internal standard) yielded 58% of **43** and 26% of the starting amine **44**.

Chlorination and Solvolysis of *p*-(*N*-*tert*-Butylamino)nitrobenzene. To a solution of 1.0 g of *p*-(*N*-*tert*-butylamino)nitrobenzene in 50 ml of 1:1 carbon tetrachloride–pentane was added 10 g of powdered calcium hypochlorite. After the mixture was stirred for 4 hr at room temperature, the salts were removed by filtration and the solution was concentrated *in vacuo* to leave the neat chloramine **42**. Infrared analysis of **42** showed the complete absence of the N–H band of the starting amine. The sample was added to a solution of 3.42 g of silver trifluoroacetate in 50 ml of methanol. Silver chloride precipitated slowly. After the mixture was stirred overnight, an iodometric test for active chlorine was negative. Excess lithium chloride was added and the silver chloride was removed by filtration. The solvent was removed on the rotary evaporator and the residue was taken up in 100 ml of ether and stirred over sodium hydroxide pellets for 1 hr. The ethereal solution was decanted and the solvent evaporated to give yellow crystals. Chromatography on Activity I basic alumina separated two compounds. The first compound eluted (hexane–ether solvent) was 761 mg (65%) of 3-chloro-4-(*N*-*tert*-butyl)nitrobenzene (**45**): mp 113–115°; ir (KBr) 6.25, 7.52, 7.69, 8.20, and 8.85 μ; nmr ($CDCl_3$) τ 8.49 (9 H, s), 7.00 (1 H, d), 1.72 (3 H, m).

Anal. Calcd for $C_{10}H_{13}N_2O_2Cl$: C, 52.52; H, 5.73; N, 12.25; Cl, 15.51. Found: C, 52.58; H, 5.75; N, 12.12; Cl, 15.50.

The second product to be eluted was starting *p*-(*N*-*tert*-butylamino)nitrobenzene (**46**).

Acknowledgment. We are indebted to the National Cancer Institute of the Public Health Service for a grant which supported this investigation.

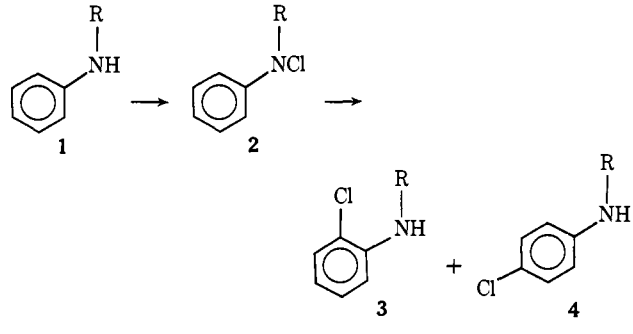
Thermal Rearrangement of *N*-Chloroanilines. Evidence for the Intermediacy of Nitrenium Ions[1]

Paul G. Gassman* and Gerald A. Campbell[2]

Contribution from the Department of Chemistry, The Ohio State University, Columbus, Ohio 43210. *Received October 1, 1971*

Abstract: The mechanism of the thermal rearrangement of *N*-alkyl-*N*-chloroanilines has been studied in both ethanol buffered with 0.1 *N* sodium acetate and 0.1 *N* acetic acid and in unbuffered ethanol. Under buffered conditions, a series of six para-substituted *N*-*tert*-butyl-*N*-chloroanilines solvolyzed at rates which correlated excellently with Brown's σ^+. A $\sigma^+\rho$ plot gave a ρ of -6.35. This showed that the mechanism involved the generation of an electron-deficient nitrogen species (anilenium ion) and chloride anion. In the presence of acid catalysis, two competing mechanisms seemed to be involved in the rearrangement of *N*-chloroanilines to *o*-chloroanilines, with one mechanism being favored by electron-donating substituents and the other mechanism being promoted by electron-withdrawing substituents.

The chlorination and bromination of the aromatic rings of anilines and related amines have been the subject of extensive discussion during the last 10 years. In general, sources of positive halogen, especially of positive chlorine, readily halogenate the aromatic nucleus when an amine function is attached to the aromatic ring. Much of the mechanistic thinking in this area has been fashioned by the careful investigations of Neale and coworkers[3] and by Haberfield and Paul.[4] These workers provided convincing evidence for the intermediacy of *N*-chloramines in the chlorination of aromatic amines by reagents such as *N*-chlorosuccinimide and calcium hypochlorite.[5,6] Experimental results already presented[1,4] leave little doubt about the validity of the hypothesis[3] that the first step involves *N*-chlorination. The major question which remained to be answered concerned the mechanism whereby **2** was converted into a mixture of **3** and **4**. We now



wish to report the details of our studies which show that simple *N*-chloramines rearrange *via* heterolytic cleavage of the N–Cl bond of **2** to yield an electron-deficient divalent nitrogen species (anilenium ion) and chloride anion.[7]

Various mechanistic routes from **2** to **3** and **4** can be postulated. Of the many possibilities, the two most attractive alternates are shown in paths a and b.[8a]

(1) Paper XXII in a series on The Chemistry of Nitrenium Ions. For the previous paper in this series, see P. G. Gassman, G. A. Campbell, and R. C. Frederick, *J. Amer. Chem. Soc.*, **94**, 3884 (1972).

(2) National Defense Education Act Fellow, 1967–1970; Stauffer Chemical Fellow, 1970–1971.

(3) R. S. Neale, R. G. Schepers, and M. R. Walsh, *J. Org. Chem.*, **29**, 3390 (1964).

(4) P. Haberfield and D. Paul, *J. Amer. Chem. Soc.*, **87**, 5502 (1965).

(5) Various other chlorinating agents have been used. For additional synthetic application and leading references, see T. A. Foglia and D. Swern, *J. Org. Chem.*, **33**, 4440 (1968); J. M. Muchowski, *Can. J. Chem.*, **48**, 422 (1970); A. M. Pinchuk, L. N. Markovskii, and I. M. Kosinskaya, *Zh. Obshch. Khim.*, **38**, 1008 (1968); and P. G. Gassman, G. A. Campbell, and G. Mehta, *Tetrahedron*, in press.

(6) For a detailed discussion of the initial *N*-chlorination of aromatic amines, see ref 1.

(7) For a preliminary report of part of this investigation, see P. G. Gassman and G. A. Campbell, *J. Amer. Chem. Soc.*, **93**, 2567 (1971).

(8) (a) An alternate possibility would involve halogen exchange between halogenated aniline and protic solvent followed by direct transfer of positive halogen from the hypohalite to the aromatic nucleus in an electrophilic halogenation. This plausible mechanism is rendered