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Electron-Transfer Substitution Reactions: Facilitation by the Cyano Group[1]

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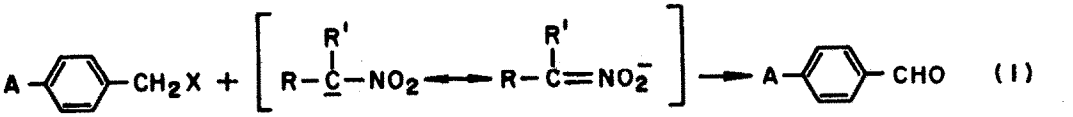
Abstract

It is now clear that a cyano group facilitates electron-transfer substitution reactions. Of particular interest is the demonstration that electron-transfer chain substitution at a saturated carbon atom has been achieved in the absence of a nitro group.

It is now well established that nucleophilic substitution at a saturated carbon atom may occur as an electron-transfer chain reaction.[2] While many examples of such processes are known, in virtually every instance a nitro group is present either in the compound undergoing substitution or in the attacking nucleophile. That this is so is a consequence of the fact that of all the commonly encountered groups, a nitro group is the most susceptible to one electron reduction.[3] Although not as readily reduced as the nitro group, the cyano group is able to undergo one electron reduction with some facility. One might anticipate, therefore, that a cyano group, while not as effective as a nitro group, should also be capable of fostering electron transfer substitution at a saturated carbon atom. In this paper we provide confirmation of this expectation.

It has long been known that, with but one exception, benzylic halides on treatment with nitroparaffin salts are transformed into aldehydes as a consequence of oxygen alkylation,[4,5] (eq 1). The sole exception is the *p*-nitrobenzyl system where carbon alkylation is observed.

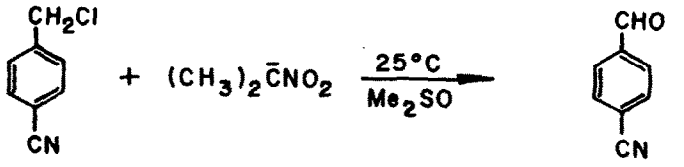


(1)

A = H, CN, CF_3, $\overset{+}{N}(CH_3)_3$, $CH_3\overset{O}{\overset{\|}{C}}$, $CH_3O\overset{O}{\overset{\|}{C}}$, Br,
X = Cl, Br, I

Since 1961 oxygen alkylation of nitroparaffin anions has been regarded as a simple S_N2 displacement.[6] Then, in 1964,[7] it was established that the carbon alkylation observed with *p*-nitrobenzyl halides derives from a multi-stage process involving one electron transfer and that, even in the *p*-nitrobenzyl system, carbon alkylation competes successfully with the reaction of eq 1 only when the leaving group is displaced with difficulty in an S_N2 reaction.

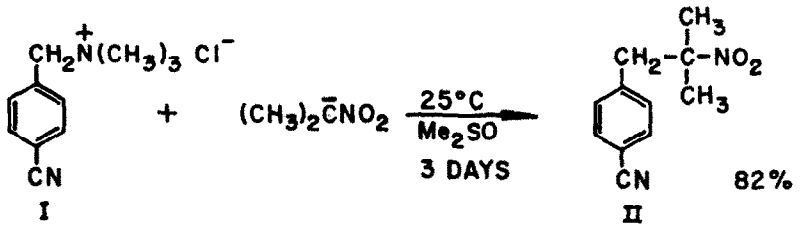
The fact that *p*-nitrobenzyl chloride, when treated with the salt of 2-nitropropane, gives a 92% yield of the carbon alkylate, whereas *p*-cyanobenzyl chloride gives the aldehyde in 81% yield (eq 2), is taken to mean that the ability of a *p*-nitro group to foster electron-



(2)

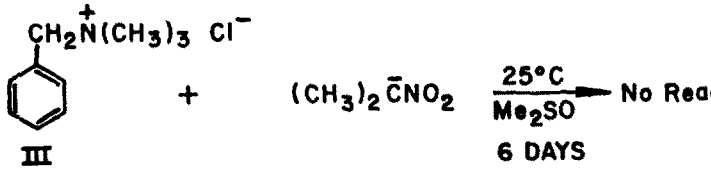
transfer suffices to overwhelm competition by the S_N2 reaction whereas a p-cyano group does not provide sufficient facilitation of the electron-transfer process to enable it to outstrip the S_N2 displacement of chlorine.

In conformity with this view it has now been found that when (p-cyanobenzyl) trimethylammonium chloride (I) is treated with the salt of 2-nitropropane for 3 days an 82% yield of the carbon alkylate (II) is obtained (eq 3). Here, with a leaving group that is more difficult to displace than chlorine, and with the facilitation provided by a p-cyano



(3)

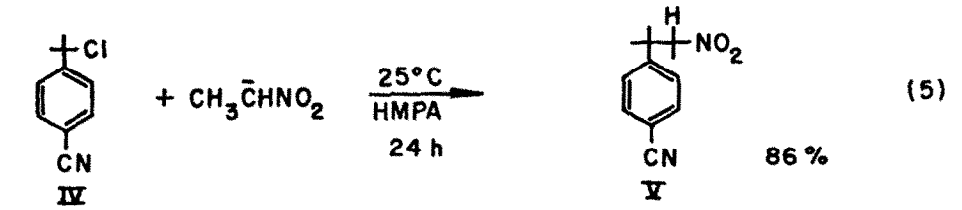
group, electron-transfer substitution takes over. That the p-cyano group does indeed play a role in the reaction of eq. 3 accords with the failure of benzyltrimethylammonium chloride (III) to react with the salt of 2-nitropropane after 6 days (eq 4).



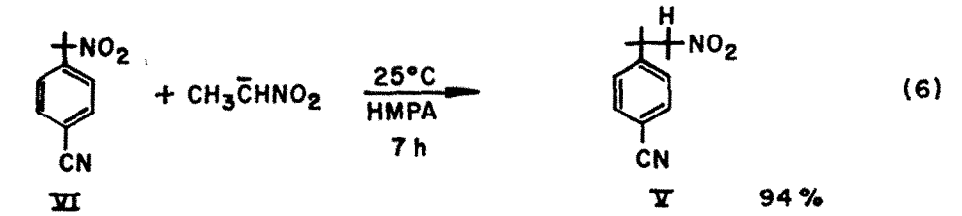
(4)

The assignment of an electron-transfer chain mechanism to the reaction of eq 3 is strongly supported by the fact that the reaction is completely inhibited by 20 mol% of m-dinitrobenzene (m-DNB) or di-tert-butyl nitroxide; indeed, even the presence of nitrobenzene results in unambiguous inhibition. Furthermore, the reaction of eq 3 does not proceed in the dark.[8]

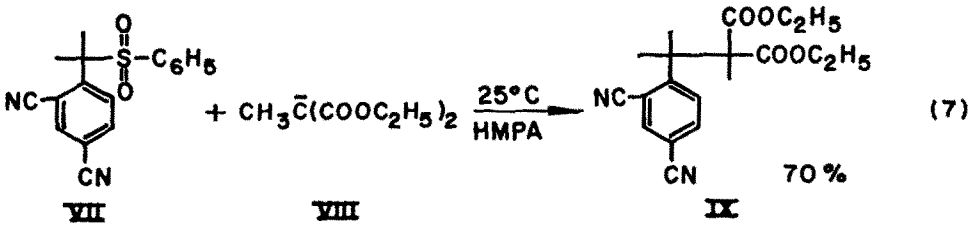
Steric hindrance provides yet another means of impeding S_N2 displacements. Although the transformation of eq 5 employs chlorine as the leaving group, the chlorine is on a tertiary carbon and, thus, the S_N2 displacement does not compete. An opportunity is thereby provided for the cyano group to facilitate electron transfer and, indeed, an 86% yield of the carbon alkylate V is obtained.[8] In accord with the view that this reaction is an electron-transfer chain process m-dinitrobenzene (m-DNB) and di-tert-butyl nitroxide inhibit it.



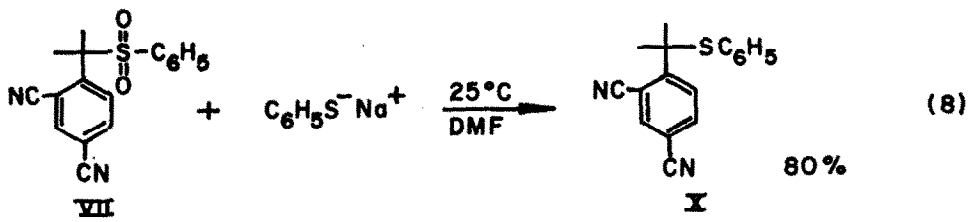
The reaction of α-nitro *p*-cyanocumeme (VI) with the salt of nitroethane (eq 6) also occurs readily and also gives an excellent yield of V; it too, is inhibited by *m*-DNB and di-*tert*-butyl nitroxide, and light[8] is required. However, as a demonstration of the ability of a cyano group to facilitate electron-transfer substitution the reaction of eq 6 leaves something to be desired for it suffers from the ambiguity introduced by the presence of a nitro group in VI.[9]



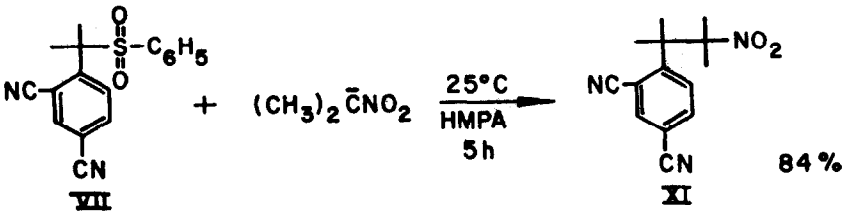
The electron-transfer chain reactions discussed up to this point have involved systems with a nitro group present in the nucleophile or in the compound undergoing substitution. We turn, now, to electron-transfer chain reactions of *o,p*-dicyano-α-phenylsulfonyl-cumeme (VII)[10], transformations which occur readily despite the complete absence of a nitro group. Thus, treatment of VII with the sodium salt of diethyl methylmalonate VIII gives a 70% yield of pure product after 24h at room temperature[8] (eq 7). That this is indeed an electron-transfer chain process is clear from the fact that this reaction does not occur in the dark and it is inhibited by 20 mol % of *m*-dinitrobenezene or by 20 mol % of di-*tert*-butyl nitroxide.



The transformations of eq 8 occurs in less than 10 min at 25°C and the pure sulfide is isolated in 80% yield. This reaction is also inhibited by di-*tert*-butyl nitroxide.



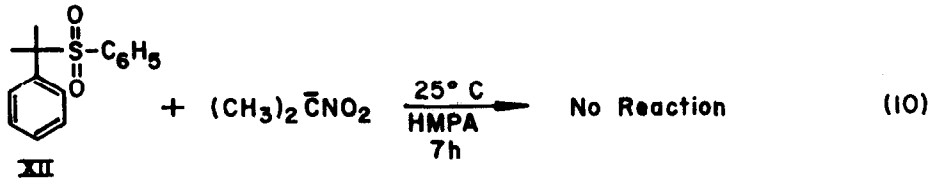
The ability of cyano groups to foster electron-transfer chain substitution is again brought home by the experiments of eq 9 and 10. For, whereas the dicyano sulfone VII reacts rapidly with the lithium salt of 2-nitropropane and gives an 84% yield of the pure



(9)

VII XI

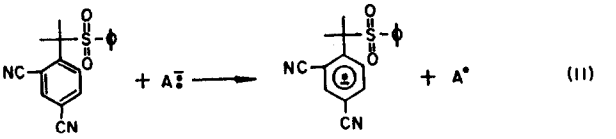
product (eq 9), there is no reaction when the unsubstituted sulfone XII of eq 10 is treated with the lithium salt of 2-nitropropane.[11]



(10)

XII

The reactions of eq 7 and 8 presumably proceed via the mechanistic sequence of eq 11-14. It is also apparent from the transformations of eq 3 and 5 that monocyano compounds readily accept one electron from nitroparaffin salts to give radical anions and that these readily lose trimethylamine, or chloride ion, thereby giving rise to the corresponding radicals: *i.e.*, the monocyano compounds exhibit characteristics analogous to those described by eq 11 and 12.



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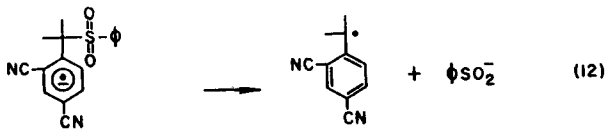

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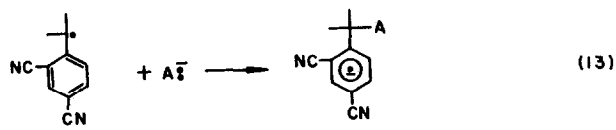

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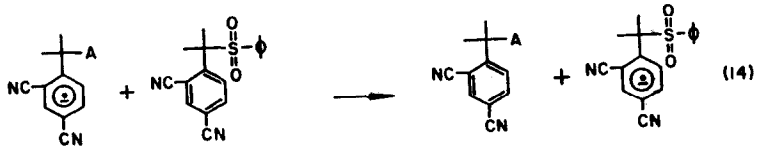


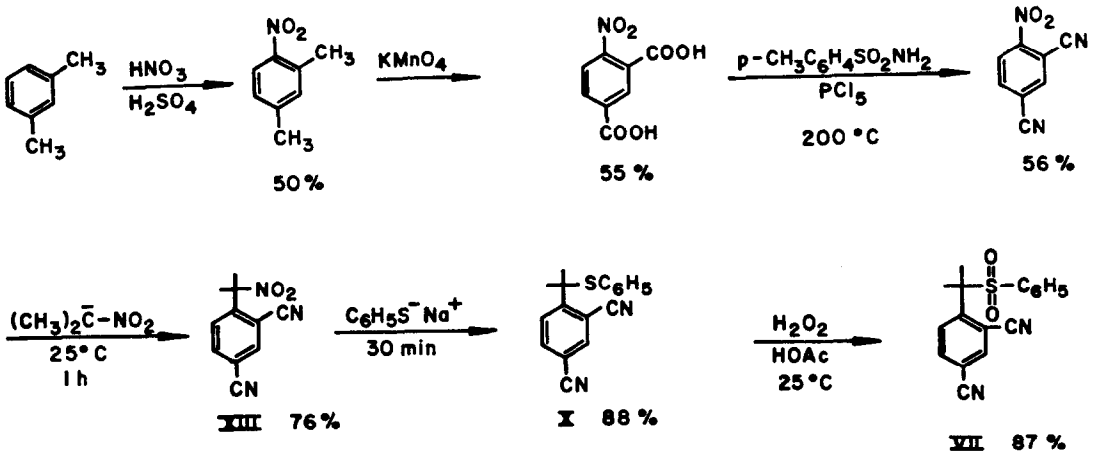
(14)

Facilitation by the cyano group of electron-transfer chain substitution must involve the cyano group's ability to delocalize an electron. That a cyano group is converted to a cyano radical anion on exposure to a "high-pressure" source of electrons such as metallic sodium or lithium anthracene is well-known.[12] But the present studies do not involve potent one-electron donors and yet a chain reaction involving radical anions and free radicals is set up under very mild conditions.

Most important of all, it has now been demonstrated for the first time that electron-transfer chain substitution can occur at a saturated carbon atom in the complete absence of nitro groups and that these reactions are synthetically valuable. Aside from their intrinsic interest, the results herein presented lead one to anticipate that electron attracting groups other than nitro and cyano, singly or in combination, will also be able to facilitate electron-transfer substitution at a saturated carbon-both chain and nonchain.

Acknowledgment We thank the National Science Foundation for supporting this investigation.

SCHEME I



Experimental Section

Solvents: HMPA, Me_2SO and DMF were purified as described earlier.[13]

CAUTION! HMPA should be handled with great care since it has been found to cause cancer in laboratory animals.[14]

The lithium salt of 2-nitropropane and the sodium salt of diethyl methylmalonate were prepared as described earlier.[15] The sodium salt of thiophenol was prepared as described for *p*-chloro-thiophenol.[15]

p-Cyanobenzyltrimethylammonium Chloride (I). A solution of 20 g (0.13 mol) of *p*-cyanobenzyl chloride[16] in 100 mL of acetone was placed in a flask fitted with a Dry Ice condenser, a drying tube and a mechanical stirrer. The reaction flask was cooled in an ice-bath and under N_2 13 g (0.22 mole) of trimethylamine was distilled into the flask. Stirring was continued for an additional 20 minutes and the resulting white crystals were isolated by filtration under N_2, and after washing with 50 mL portions of acetone, benzene and diethyl ether were dried at 0.1 mm.

Anal. Calc for $C_{11}H_{15}N_2Cl$: C, 62.70; H, 7.18; N, 13.29; Cl, 16.83; Found: C, 62.66; H, 6.86; N, 13.09; Cl, 17.13

The Reaction of *p*-Cyanobenzyltrimethylammonium Chloride (I) with the Lithium Salt of 2-Nitropropane.

Under argon (freeze-pump-thaw technique)[17] 1.055 g (5 mmol) of *p*-cyanobenzyltrimethylammonium chloride and 2.375 g (25mmol) of the lithium salt of 2-nitropropane in 50 mL of Me_2SO were allowed to react while being stirred and exposed to light.[8] After 3 days the resulting solution was poured into 500 mL of H_2O, extracted with diethyl ether and then with benzene. The combined extracts were washed with H_2O, dried ($MgSO_4$), and the solvents removed under reduced pressure. The resulting yellow oil (0.945 g) was chromatographed on silica gel using benzene for elution and then benzene-diethyl ether (20:1). The 0.820 g of II obtained from the benzene-diethylether eluates when kugelrohr distilled at 115°C/0.6 mm gave 0.774 g (77% yield of pure 2-(*p*-cyanobenzyl)-2-nitropropane (II); mp 39-40°C. NMR ($CDCl_3$) δ 1.58 (s, 6 H), 3.35 (s, 2 H), 7.41 (q, 4 H). IR (melt) μ4.50 (CN); 6.54 and 7.46 (NO_2).

Anal. Calc for $C_{11}H_{12}N_2O_2$: C, 64.69; H, 5.92; N, 13.72. Found: C, 64.71; H, 5.86; N, 13.50.

The benzene eluates, after removal of the benzene, were subjected to preparative TLC using ethyl acetate-hexane (1:4). In this way an additional 0.016 g of II, and 0.021 g (3% yield) of *p*-cyano-β,β-dimethylstyrene *vide infra* were isolated. Since the styrene derives from (II), this represents a total yield of 82%.[18,19]

A duplicate of this reaction was carried out in the presence of 0.168 g (1 mmol) of *m*-dinitrobenzene (*m*-DNB). Work up gave 0.121 g of crude product as a red liquid whose NMR and VPC analyses failed to reveal the presence of II, or any oxygen alkylation products.

A second duplicate conducted in the presence of 0.615 g (5 mmol) of nitrobenzene gave 0.560 g of a yellow liquid as the crude product. Column chromatography, preparative TLC and kugelrohr distillation gave 0.032 g (3% yield) of II, mp 40-41°C and 0.009 g (*ca*. 1% yield) of *p*-cyano-β,β-dimethylstyrene. Thus, in the presence of 100 mol % of nitrobenzene only 4% C-alkylation occurs.

A third duplicate of this reaction conducted in the presence of 0.144 g (1 mmol) of di-*t*-butylnitroxide gave 0.086 g of an oil as the crude product. Preparative TLC (EtOAc-Hexane 1:4) followed by kugelrohr distillation at 115°C/0.3 mm yielded 0.015 g of a mixture whose NMR indicated that it contained 77% (II). This corresponds to a *ca*. 1% yield of II.

p-Cyano-β,β-Dimethyl Styrene.

This was prepared from *p*-cyano-benzaldehyde and triphenylphosphonium iodide by the Wittig reaction; n_D^{23} 1.5705; ^{1}HNMR($CDCl_3$) δ 1.8-2.0 (d of d, 6 H), 6.25 (s, 1 H), 7.2-7.6 (ABq 4 H). IR (neat) μ4.55. Anal. Calc for $C_{11}H_{11}N$: C, 84.04; H, 7.05; N, 8.91. Found: C, 84.04; H, 7.26; N, 8.75.

The Reaction of *p*-Cyanobenzyl Chloride with the Lithium Salt of 2-Nitropropane.

Under N_2 a stirred solution of 1.52 g (10 mmol) of *p*-cyanobenzyl chloride and 0.480 g (5 mmol) of the lithium salt of 2-nitropropane in 100 mL of Me_2SO was allowed to react for 2 h. Titration for chloride revealed that 98% of the expected amount of Cl^- had been formed. The reaction mixture was treated for 2 h at *ca*. 10°C with 9.7 mL (100 mmol) of trimethylamine to remove the excess *p*-cyanobenzyl chloride. The reaction product was poured into one liter of ice water, extracted with CH_2Cl_2 and the CH_2Cl_2 extracts washed with water and dried

(Na_2SO_4). Removal of the CH_2Cl_2 gave 0.637 g of a white solid which when sublimed at 70-90°C/0.4 mm provided 0.528 g (81% yield) of *p*-cyanobenzaldehyde, mp 97-100°C; lit[21] mp 101-102°C. ^{1}HNMR ($CDCl_3$) δ 7.72-8.10 (q, 4H), 10.06 (s, 1 H). IR (KBr) μ 3.66, 4.50, 5.90, 12.11.

The Reaction of *p*-Cyanocumyl Chloride (IV) with the Lithium Salt of Nitroethane.

Under argon (freeze-pump-thaw procedure)[17] 0.180 g (1 mmol) of *p*-cyanocumyl chloride and 0.162 g (2 mmol) of the lithium salt of nitroethane in 10 mL of HMPA were allowed to react for 24 h while being stirred and held under the light bank.[8] The resulting yellow solution was cooled in an ice-bath and a cold solution of 0.369 g of urea in 1.8 mL of 20% HOAc-80% H_2O was added. After stirring for 10 min. the cold reaction product was poured into 200 mL of distilled H_2O, extracted with diethyl ether and with benzene. The combined extracts were washed with H_2O, dried ($MgSO_4$) and the solvents removed under reduced pressure. This gave 0.223 g of a crude product which was subjected to preparative TLC on a silica gel plate using $CHCl_3$. The resulting 0.196 g when kugelrohr distilled at 109°C/0.15 mm. gave 0.188 g (86% yield) of 2-(*p*-cyanophenyl)-2-methyl-3-nitrobutane (V); mp 56-58°C. The IR and NMR spectra were identical with those of an analytically pure sample. (*vide infra*).

A duplicate experiment was carried out in the presence of 0.032 g (0.2 mmol) of *m*-DNB. On work up 0.225 g of a red liquid was obtained. By preparative TLC, kugelrohr distillation at 0.15 mm, NMR and IR examination of the various fractions it was established that the red liquid was a complex mixture *ca*. 5% of which consisted of the starting chloride (IV); 0.032 g (20% yield) *p*-cyanocymyl alcohol (mp 49-50°C), *p*-cyanocumene (4% yield), *p*-cyano-α-methylstyrene (*ca*. 1% yield); 2-(*p*-cyanophenyl-4-nitropentane (the Michael adduct of nitroethane to *p*-cyano-α-methyl styrene) *ca*. 11% yield; and, finally, a 19% yield of V. Clearly 20 mol % of *m*-dinitrobenzene inhibits the electron-transfer substitution process and provides an opportunity for side reactions to compete.

A second duplicate experiment in which 0.015 g (0.1 mmol) of di-*tert*-butyl nitroxide was employed gave a 14% recovery of the starting chloride (IV), a 2% yield of *p*-cyano-α-methylstyrene, a 14% yield of 2-(*p*-cyanophenyl)-4-nitropentane and a 42% yield of *p*-nitrocumyl alcohol. A trace of V was detected by NMR. Thus 10 mol % of the nitroxide completely inhibits the reaction of eq 5.

Finally, a duplicate experiment was carried out in total darkness by wrapping the system in aluminum foil and placing it in the darkroom. After the usual work up a 15% recovery of the chloride IV was obtained along with a 41% yield of *p*-cyanocumyl alcohol and a 4% yield of *p*-cyano-α-methylstyrene. The Michael adduct of the styrene with nitroethane was produced in a *ca*. 6% yield along with a *ca*. 12% yield of V. Clearly, light produces a large rate increase in the reaction of eq 5.

The Reaction of *p*-Cyano-α-Nitro Cumene (VI) with the Lithium Salt of Nitroethane.

Under nitrogen a stirred mixture of 0.162 g (2 mmol) of the lithium salt of nitroethane and 0.190 g (1 mmol) of *p*-cyano-α-nitrocumene[22] (VI) in 10 mL of HMPA was allowed to react for 7.5 h under the light bank.[8] The resulting pale yellow solution was cooled in an ice bath and treated with a cold solution of 0.396 g (6 mmol) of urea in 1.8 mL of 20% HOAc-80% H_2O. After stirring for 10 minutes at 0°C the product was poured into 200 mL of H_2O and extracted with diethylether and with benzene. The combined extracts were washed with H_2O and dried ($MgSO_4$). Removal of the solvents gave 0.246 g of a yellow liquid which after kugelrohr distillation at 122°C/0.1 mm yielded 0.205 g (94% yield) of 2-*p*-cyanophenyl)-2-methyl-3-nitrobutane (V) mp 57-58°C. NMR ($CDCl_3$) δ [1.4 (d); 1.49 (s) 9 H]; 4.82 (q, 1 H); 7.4-7.8 (ABq, 4 H). IR (melt) μ 4.48, 6.48. Anal. Calc for $C_{12}H_{14}N_2O_2$: C, 66.04; H, 6.47; N, 12.84. Found: C, 65.83; H, 6.26; N, 12.64.

On standing the mp of the 2-*p*-cyanophenyl)-2-methyl-3-nitrobutane (V) changed from 57-58°C to 62-65°C in three weeks. The IR and NMR of the 62-65°C material, however, remained identical with the IR and NMR of the 57-58°C melting material. After 8 months the mp had become 65-66°C and elemental analysis gave the following results: C, 66.28; H, 6.69; N, 12.98. Clearly, the higher melting material is a second crystalline form of 2-(*p*-cyanophenyl)-2-methyl-3-nitrobutane(v).

A duplicate experiment conducted in the presence of 0.034 g (0.20 mmol) of *m*-DNB resulted in a 72% recovery (0.136 g) of pure *p*-cyano-α-nitrocumene.

A second duplicate conducted in the presence of 0.014 g (0.1 mmol) of di-*tert*-butyl nitroxide resulted in a 0.172 g recovery (91%) of the starting *p*-cyano-α-nitrocumene.

Finally, when a duplicate experiment was carried out in the dark 0.168 g (88%) of the pure *p*-cyano-α-nitrocumene was recovered. There was no indication of the formation of V in the dark, *m*-DNB or nitroxide experiments.

Preparation of α-Nitrocumene ($C_6H_5CMe_2NO_2$).

(a) N-α-Cumyl Formamide.

This was prepared by the Ritter reaction[23] from α-methylstyrene. For analysis a sample was kugelrohr distilled at 93°C/0.1 mm; n_D^{23} = 1.5371; NMR ($CDCl_3$) δ 1.53 (s, 3 H); 1.57 (s, 3 H); 7.0-8.2 (M, 7 H). IR (neat) μ 3.06, 3.65, 6.0; Anal. Calc for $C_{10}H_{13}NO$: C, 73.59; H, 8.03; N, 8.58. Found: C, 73.44; H, 7.82; N, 8.40.

(b) α-Aminocumene.

The formamide on hydrolysis with hot aq. NaOH gave α-aminocumene, a colorless liquid bp 92-93°C at 26 mm.; n_D^{24} 1.5174. NMR ($CDCl_3$) δ 14.1 (S, 8 H); 7.1-7.2 (M 5 H); IR (neat) μ 2.98, 3.07. Anal. Calc for $C_9H_{13}N$: C, 79.95; H, 9.69; N, 10.36. Found: C 80.03; H, 9.74; N, 10.55.

(c) α-Nitrocumene.[24]

Into a 5 L flask equipped with an efficient stirrer, a reflux condenser and a thermometer was placed 1,125 mL of acetone, 59.9 g (0.45 mol) of α-aminocumene, 300 mL of H_2O and 68 g (0.57 mol) of anhydrous $MgSO_4$. Then, over a 1 h period 430 g (2.72 mol) of $KMnO_4$ was added; care was taken not to allow the $KMnO_4$ to cake up on the bottom of the flask. The temperature of the reaction mixture was held between 25-30°C by cooling. After the $KMnO_4$ addition the reaction mixture was stirred for 46 h, care being taken to maintain the reaction temperature no higher than 30°C. The reaction mixture was worked up by filtering off the MnO_2, washing the MnO_2 with benzene and extracting the aqueous phase with benzene. The combined benzene extracts were washed with H_2O, with 5% aq HCl and with H_2O. After drying (Na_2SO_4) and removal of the benzene 74.0 g of crude material was obtained. Chromatography on acid washed alumine using hexane and ethyl acetate gave 51.6 g of crude α-aminocumeme: this was fractionally distilled at 5 mm through a tantalum packed column. In this way 34.6 g (47% yield) of pure α-nitrocumene was obtained; n_D^{25} 1.5178; NMR ($CDCl_3$) δ 1.95 (s, 6 H); 7.39 (s, 5 H) IR (neat) μ 6.55, 7.44. Anal. Calc for $C_9H_{11}NO_2$; C, 65.44; H, 6.71; N, 8.48. Found: C, 65.60; H, 6.72; N, 8.50.

The Reaction of α-Nitrocumene with the Lithium Salt of Nitroethane.

Under argon (freeze-pump-thaw procedure[17]) 0.065 g (1 mmol) of α-nitrocumene and 0.162 g (2 mmol) of the lithium salt of nitroethane in 10 mL of HMPA were allowed to react for 45 h with stirring and exposure to the light bank.[8] The yellow solution was cooled in an ice-bath and treated with a cold solution of 0.369 g of urea in 1.8 mL of 20% HOAc-80% H_2O. After stirring for 10 minutes in the cold the product was poured into 200 mL of H_2O and extracted with pentane. The pentane extracts were washed with H_2O, dried ($MgSO_4$) and the pentane removed in the cold under reduced pressure. This gave 0.178 g of a colorless liquid which was prep TLC'd on silica gel using EtOAc-Hexane (1:9). Fraction one contained 0.018 g of a solid mp 103-110°C. Recrystallization from dry MeOH yielded 0.011 g (9% yield) 2,3-diphenyl-2,3-dimethylbutane; white needles mp 116-117°C, lit[25] mp 118-119°C; M^+ 238. NMR ($CDCl_3$) δ 1.28 (s, 12 H); 7.15 (m) 10 H. Anal. Calc for $C_{18}H_{22}$: C, 90.70; H, 9.30; Found: C, 90.65; H, 9.30.

This was followed by a fraction containing 0.152 g of a colorless liquid which on kugelrohr distillation at 57°C/0.1 mm yielded 0.143 g (74% yield) of 2-phenyl-2-methyl-3-nitrobutane, a colorless liquid; n_D^{22} 1.5200; which was pure by TLC on silica gel (1 % EtOAc-90% Hexane) and by VPC. NMR ($CDCl_3$) δ 1.29 (d, 3 H); 1.44 (s, 6 H); 4.86 (q, 1 H), 7.34 (m, 5 H). IR (neat) μ 6.52, 7.47. Anal. Calc for $C_{11}H_{15}NO_2$: C, 68.37; H, 7.82; N, 7.01. Found: C, 68.14; H, 7.59; N, 7.25.

A duplicate experiment conducted in the presence of 20 mol % (0.20 mmol) of *m*-DNB gave *ca*. a 4% yield of 2-phenyl-2-methyl-3-nitrobutane and a 77% recovery of α-nitrocumene.

A second duplicate was completely inhibited by 0.09 mmol (9 mol %) of di-*t*-butyl nitroxide. Here 73% of the starting α-nitrocumene was recovered in pure form and there was no indication of reaction.

Finally, a third duplicate experiment conducted in the dark gave an 83% recovery of pure α-nitrocumene. Thus the reaction of α-nitrocumene with the lithium salt of nitroethane clearly is an electron-transfer chain reaction.

The Synthesis of *o,p*-Dicyano-α-Phenylsulfonylcumene (VII).

(a) 1,3-Dimethyl-4-Nitrobenzene.

Nitration of *m*-xylene[26] using 70% HNO_3 and concentrated H_2SO_4 at 30°C gave a mixture of isomers from which a 52% yield of 1,3-dimethyl-4-nitrobenzene was isolated by fractional distillation: bp 121°C/14 mm. The NMR of this compound was identical with Sadtler NMR # 21150.

(b) 4-Nitroisophthalic Acid.

Into a 3 L flask fitted with a thermometer, an efficient stirrer and a reflux condenser was placed 1 L of H_2O, 60.4 g (0.4 mol) of 1,3-dimethyl-4-nitrobenzene and 316 g (2 mols) of $KMnO_4$. The mixture was cautiously heated to 85°C and the internal temperature maintained at 85°C using an ice bath to control the initial exothermic reaction. Then heating was instituted and the mixture was refluxed for *ca*. 2 h. Unreacted nitroxylene (10.2 g) was recovered by steam distillation after which the hot reaction mixture was filtered through Celite, cooled and acidified with H_2SO_4. Diethyl ether extraction gave 54.8 g of crude acid, mp 244-250°C. This was dissolved in 200 mL of hot HOAc and the solution was diluted to 6 L with $CHCl_3$ and then chromatographed on silica gel. Elution with 3% HOAc-97% $CHCl_3$ gave material which was discarded. Then elution with 1:1 HOAc-$CHCl_3$ gave 44.5 g of yellow solid mp 249-253°C. This material was dissolved in Et_2O and precipitated with hexane, yielding 38.9 g (55% yield) of 4-nitroisophthalic acid mp 253-254°C, lit[27] mp 258-259°C.

(c) 2,4-Dicyanonitrobenzene[28]

A stirred mixture of 21.1 g (0.1 mol) of 4-nitroisophthalic acid, 37.6 g (0.22 mol) of *p*-toluenesulfonamide, and 91.5 g (0.44 mol) of PCl_5 was heated at 200-205°C for 30 min., cooled, and then 200 mL of $CHCl_3$ was added. The mixture was refluxed for 30 minutes and then chromatographed on silica gel using $CHCl_3$ and $CHCl_3$-EtOAc (9:1). A yellow solid was obtained. Kugelrohr distillation at 124°C/0.005 mm gave 10.2 g of yellow solid mp 123-125°C. Recrystallization from $CHCl_3$-hexane gave 9.8 g (56% yield of 2,4-dicyanonitrobenzene, mp. 124-125°C. NMR ($CDCl_3$) δ 8.06 (d of d, 1 H); 8.18 (d, 1 H); 8.44 (d, 1 H). IR (KBr) μ 4.45m 6.58 and 7.45. Anal. Calc for $C_8H_3N_3O_2$: C, 55.50; H, 1.75; N, 24.27. Found: C, 55.40; H, 1.86; N, 24.36.

(d) *o,p*-Dicyano-α-Nitrocumene,[22] (XIII).

Under N_2 a stirred solution of 8.69 g (91.5 mmol) of the lithium salt of 2-nitropropane in 120 mL of Me_2SO was treated with 13.15 g (76 mmol) of 2,4-dicyano-nitrobenzene for 1.5 h. Work up yielded 14.8 g of a yellow solid which was chromatographed on silica gel employing EtOAc-hexane (1:4) and, then 1:1, for elution. This gave 13.2 g of a white solid mp 112-114°C. Recrystallization from EtOAc-hexane yielded 12.37 g (76% yield) of *o,p*-dicyano-α-nitrocumene; white needles mp 113-114°C. NMR ($CDCl_3$) δ 2.13 (s, 6 H); 7.66 (d, 1 H); 7.86-8.10 (m, 2 H). IR (KBr) μ 4.50, 4.54, 6.58, 7.50. Anal. Calc for $C_{11}H_9N_3O_2$: C, 61.39; H, 4.22; N, 1952. Found: C, 61.23; H, 4.46; N, 19.26.

(e) *o,p*-Dicyano-α-Thiophenylcumene (X).

Under N_2 1.075 g (5 mmol) of *o,p*-dicyano-α-nitrocumene (XIII) was allowed to react with 2.64 g (20 mmol) of sodium thiophenoxide in 50 mL of DMF with stirring and exposure to light.[8] After 30 minutes the orange solution was poured into H_2O and extracted with Et_2O and with benzene. The combined extracts were washed with H_2O and dried ($MgSO_4$). Removal of solvents gave 1.535 g of an oil which when chromatographed on silica gel using EtOAc-hexane (1:19) and then (1:4) yielded 1.371 g of a solid mp 84-86°C; recrystallization from hexane gave 1.217 g (88% yield) of *o,p*-dicyano-α-thiophenylcumene (X); white needles, mp 85.5-86.5°C. NMR ($CDCl_3$) δ 1.85 (s, 6 H): 7.00-7.40 (m, 6 H) 7.63 (d of d, 1 H); 8.00 (d, 1 H).

IR (KBr) μ 4.51. Anal. Calc for $C_{17}H_{14}N_2S$: C, 73.35; H, 5.07; N, 10.06; S, 11.52. Found: C, 73.37; H, 4.83; N, 9.79; S, 11.38.

In a separate experiment a second crystalline form of X was obtained as diamond shaped plates, mp 89-90°C, which had the same NMR, IR and TLC retention time as the 85.5-86.5°C melting form. Elemental analysis confirmed that we indeed deal with a dimorphic form of X. Found: C, 73.38; H, 5.20; N, 10.21; S, 11.45.

(f) *o,p*-Dicyano-α-Phenylsulfonylcumene (VII).

A solution of *o,p*-dicyano-α-thiophenylcumene (X) 1.390 g (5 mmol) in 10 mL of acetic acid was treated with 2 mL of 30% H_2O_2 for 24 h. The product was poured into 200 mL of H_2O containing 2 g of NaCl and extracted with $CHCl_3$. The extracts were washed with aqueous $NaHCO_3$, with H_2O and dried ($MgSO_4$). Removal of the $CHCl_3$ left 1.509 g of a white solid, mp 179-182°C. Recrystallization from ethyl acetate-hexane gave 1.348 g (87% yield) of *o,p*-dicyano-α-phenylsulfonylcumene (VII) mp 183-184°C. NMR ($CDCl_3$) δ 2.03 (s, 6 H); 7.40-7.98 (m, 8 H). IR (KBr) μ 4.50, 7.75, 8.73 and 8.83. Anal. Calc for $C_{17}H_{14}N_2SO_2$: C, 65.79; H, 4.55; N, 9.03; S, 10.33. Found: C, 65.81; H, 4.78; N, 8.92; S 10.23.

The Reaction of *o,p*-Dicyano-α-Phenylsulfonylcumene (VII) With The Sodium Salt of Diethyl Methylmalonate(VIII).

Under N_2 0.980 g (5 mmol) of the sodium salt of diethyl methylmalonate (VIII) in 10 mL of HMPA was allowed to react with 0.310 g (1 mmol) of VII), under the light bank.[8] After being stirred for 24 h the reaction mixture was worked up as usual. The 0.670 g of crude product was kugelrohr distilled at 70°/0.005 mm; this removed 0.316 g of diethyl methylmalonate; continued distillation at 127°C/0.005 mm yielded 0.281 g of oil. Prep TLC on silica gel using 20% (EtOAc-80 hexane for elution gave 0.244 g of an oil which on kugelrohr distillation at 140°C/0.005 mm yielded *ca*. 240 g of pure IX (70% yield). The NMR and IR of this product were identical with those of the analytically pure 2-(*o,p*-dicyanophenyl)-2-methyl-3,3-dicarboethoxybutane (IX) described below.

A duplicate experiment was carried out in the presence of 0.033 g (0.20 mmol) of *m*-DNB. Work up gave 0.922 g of crude product. Kugelrohr distillation at 70°C/0.005 mm removed 0.465 g of diethyl methylmalonate. By NMR The residual 0.289 g contained none of the alkylate IX. Prep TLC of the 0.289 g on silica gel using EtOAc-$CHCl_3$ (1:9) yielded 0.174 g of a yellow solid which on recrystallization from EtOAc-hexane gave 0.157 g (51% recovery) of VII; mp 183-184°C NMR and IR identical with those of pure VII.

The NMR of a synthetic mixture of IX (3%) and VII (97%) showed that as little as 3% of the alkylate IX could be unequivocally detected.

A second duplicate employing 0.029 g (0.20 mmol) of di-*tert*-butylnitroxide gave 1.324 g of crude product. The residue 0.253 g of yellow solid remaining after removal of diethyl methylmalonate, had an NMR spectrum which showed the absence of the alkylate IX. The 0.253 g on prep TLC and recrystallization from EtOAc-hexane yielded 0.206 g (66% recovery) of VII mp 182.5-184°C. NMR and IR identical with those of pure VII.

A third duplicate experiment in the dark after work up gave no evidence of the presence of the alkylate IX. Sixty-nine percent of the pure starting sulfone VII was recovered (0.215 g); mp 182.5-184°C; the NMR and IR were identical with those of the pure starting material VII.

The Reaction of *o,p*-Dicyano-α-Phenylsulfonylcumene (VII) with Sodium Thiophenoxide.

Under N_2 0.528 g (4 mmol) of sodium thiophenoxide in 10 mL of DMF was treated with 0.310 g (1 mmol) of VII. The resulting orange solution was stirred for 10 minutes under the light bank[8] and then worked up as usual. The 0.329 g of crude product was prep TLC'd on silica gel using 20% EtOAc-80% hexane to give 0.285 g of a solid. Recrystallization from hexane yielded 0.199 g of *o,p*-dicyano-α-thiophenylcumene (X) mp 85-86°C. The mp of a mixture with analytically pure X (mp. 85.5-86.5°C) was undepressed and the NMR and IR spectra were identical with those of pure X (*vide supra*). Evaporation of the EtOAc-hexane mother liquors gave 0.058 g of a solid which, after recrystallization from hexane, yielded an additional 0.023 g of pure X. The total yield of pure X was thus 0.222 g (80%).

A duplicate experiment conducted in the presence of 0.144 g (1 mmol) of di-*tert*-butyl nitroxide on the usual work up gave 0.353 g of crude product. This when prep TLC'd on silica gel using 10% EtOAc-90% $CHCl_3$ yielded 0.296 g of solid which on recrystallization from EtOAc-hexane gave 0.275 g (89% recovery) of pure *o,p*-dicyano-α-phenylsulfonylcumene VII, mp 182.5-184°C. The mp of a mixture was undepressed and the NMR and IR spectra were identical with those of the pure starting VII. Since the presence of X at the 3% level in a mixture with 97% VII could be detected unequivocally by NMR, it is clear that complete inhibition had been observed.

Reactions of *o,p*-Dicyano--α-Nitrocumene (XIII).

(a) With the Lithium Salt of 2-Nitropropane.

Under N_2 0.215 g (1 mmol) of XIII was treated with 0.480 g (5 mmol) of the lithium salt of 2-nitropropane in 10 mL of HMPA. The solution was stirred for 5 h under the light bank[8] and then worked up. The crude product 0.264 g, was kugelrohr distilled at 116°C/0.008 mm to give 0.237 g of a solid mp 161-162°C. Recrystallization from methanol yielded 0.221 g (86% yield) of white crystals of 2-(*o,p*-dicyanophenyl)-2,3-dimethyl-3-nitrobutane (XI), mp 162-163°C. NMR ($CDCl_3$) δ 1.68 (s, 6 H); 1.76 (s, 6 H); 7.54 (d, 1 H); 7.81 (d of d, 1 H); 8.0 (d, 1 H). IR (KBr) μ 4.47, 6.57, 7.48. Anal. Calc for $C_{14}H_{15}N_3O_2$: C, 65.36; H, 5.88; N, 16.33. Found: C, 65.13; H, 5.65; N, 16.12.

(b) With the Sodium Salt of Methyl Diethylmalonate VIII.

Under N_2 a stirred solution of 0.980 g (5 mmol) of (VIII) in 10 mL of HMPA was treated with 0.215 g (1 mmol) of *o,p-dicyano*-a-nitrocumene (XIII).[8] After 24 h the orange solution was worked up. The crude product, 0.631 g of an oil was kugelrohr distilled at 48°C/0.001 mm; this removed 0.180 g of diethylmethylmalonic ester. When the temperature was raised 0.292 g of an oil distilled at 124°C/0.005 mm. Prep TLC of this oil on silica gel using EtOAc (20%)-hexane (80%) gave 0.244 g of an oil which on kugelrohr distillation at 138°C/0.005 mm provided 0.236 g (69% yield) of pure (IX). NMR ($CDCl_3$) δ 1.2 (t, 6 H); 1.55 (s, 3 H); 1.85 (s, 6 H); 4.17 (q, 4 H); 7.73-8.00 (m, 3 H). IR (neat) μ 4.48, 5.82, Calculated for $C_{19}H_{22}N_2O_4$: C, 66.65; H, 6.48; N, 8.18. Found: V, 66.60; H, 6.69; N, 8.02.

This reaction is completely inhibited by 20 mol % *m*-DNB and by 20 mol % of di-*tert*-butylnitroxide; and in the dark there is virtually no reaction.

The Reaction of *o,p*-Dicyano-α-Phenylsulfonylcumene (VII) with the Lithium Salt of 2-Nitropropane.

Under N_2, a stirred solution of the lithium salt of 2-nitropropane (0.480 g, 5 mmol) in 10 mL of HMPA was treated with 0.310 g (1 mmol) of (VII), the orange solution was allowed to react for 5 h in the light.[8] On work up 0.266 g of a yellow solid was obtained. This on kugelrohr distillation at 142°C/0.002 mm yielded 0.253 g of solid. Recrystallization from methanol provided 0.216 g (84% yield) of pure (XI); mp 162.5°-164°C. The mp of a mixture with an analytically pure sample of XI was undepressed and the NMR and IR spectra were identical with those of the analytical sample.

The reaction of eq 9 is completely inhibited by *m*-DNB at the 20 mol% level and, also, by di-*tert*-butylnitroxide at the 20 mol % level.

A duplicate experiment conducted in total darkness produced *ca*. 25% of the pure carbon alkylate XI. Thus the reaction of eq 9 has a definite, albeit not very large light effect.

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(4) The oxygen alkylate of a nitroparaffin anion is unstable and breaks down to give the carbonyl compound derived from the alkylating agent.

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(8) The reaction flask was held under two 20-W ordinary fluorescent lights.

(9) That this is not an idle worry is clear from the fact that α-nitrocumene ($C_6H_5CMe_2$-NO_2) reacts with the lithium salt of nitroethane *via* the electron-transfer chain pathway to give 2-methyl-2-phenyl-3-nitrobutane in 74% yield after 45 h (See Experimental Section).

(10) The synthesis of the dicyano sulfone (VII) is outlined in Scheme I.

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(18) Compound II on exposure to an Me_2SO solution of the lithium salt of 2 nitropropane gives an 8% yield of p-cyano-β,β-dimethyl-styrene after 24 h.

(19) When the reaction of eq 3 is run for 24 h a 59% yield of (II) is obtained. This suggested that the progressive slow down in the reaction of eq 3 derives from the nitrous acid produced in the elimination process which converts II into *p*-cyano-β,β-dimethyl-styrene. Nitrous acid rapidly nitrosates secondary nitroparaffin anions to give the α-nitrosonitro compound (*i.e.* the pseudo-nitrole). Since nitroso compounds scavenge free radicals[20] it is not surprising that the reaction of eq 3 is completely inhibited by the pseudonitrole of nitrocyclohexane.

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