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Titanium(III) Chloride Mediated Reduction of Dicyanoalkenes

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The reaction of substituted dicyanoalkenes with aqueous titanium(III) chloride was examined. The dicyanoalkenes, which showed irreversible reduction characteristics on cyclic voltammograms, (typically, 2-cyano-3-phenylpropenenitrile), afforded cyclized and/or uncyclized hydrodimers, while those characterized by reversible reduction behavior, (typically, 2-cyano-3,3-diphenylpropenenitrile), yielded the corresponding saturated dinitriles. The reduction mechanism has been rationalized by taking account of the electron transfer from the Ti(III) species to the dicyanoalkenes, followed by protonation, or dimerization and cyclization.

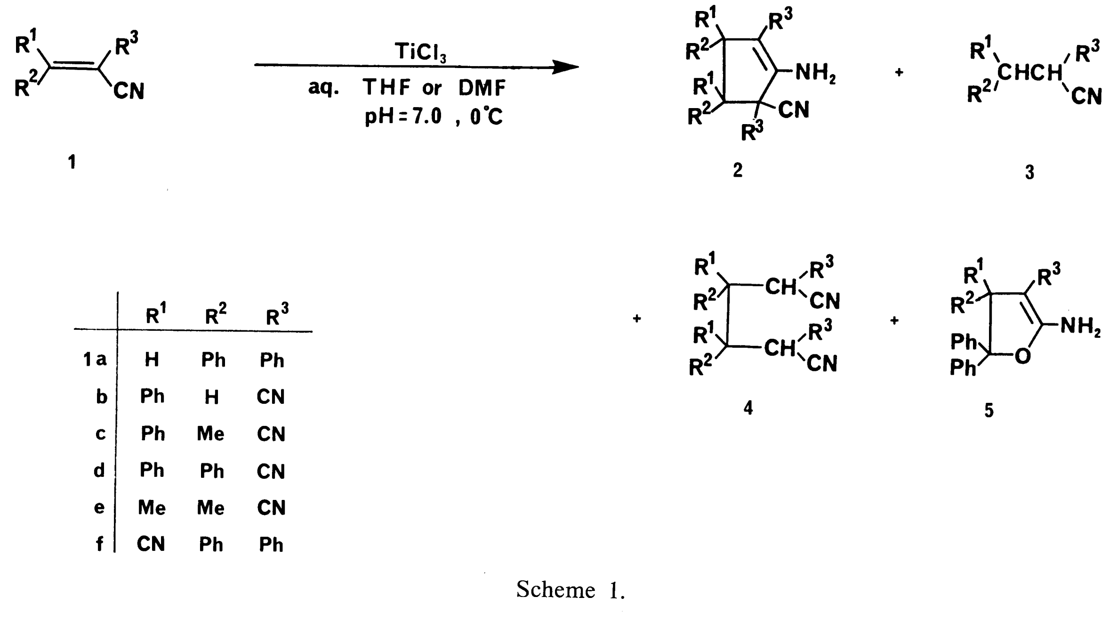
There have been much studies of the titanium(III) chloride mediated reduction of a variety of organic functionalities.[1] Titanium(III) chloride is certainly a mild ready-to-use reducing agent; we have recently reported that the reduction of nitroalkenes by aqueous titanium(III) chloride gives the corresponding carbonyl compounds, oximes, divinylamines, and pyrroles; the product distribution was controlled by the natures and numbers of the substituents of the substrates.[2] Although low-valent titanium species reductively removed the cyano groups from certain unsaturated compounds,[3] the reactions of cyanoalkenes with titanium(III) chloride have not yet been reported. In this paper we describe the titanium(III) chloride-mediated reduction of some dicyanoalkenes. The product distribution and the proposed reaction mechanism are given in connection with those for the reduction of nitroalkenes.

Results and Discussion

The reduction procedure was similar to that utilized for the reduction of nitroalkenes;[2] $TiCl_3$ was in aqueous THF or DMF (pH 7) at 0 °C. Although 2,3-diphenylpropenenitrile (**1a**) was not reduced at all, dicyanoalkenes (**1b**—**f**) were readily reduced to give their respective products (Scheme 1). The product distribution given in Table 1 was governed by the substituents of the dicyanoalkenes and the cyclic voltammetric behavior of the substrates shown in Table 2.

All of the reductions were thought to proceed through anion radical intermediates formed by an initial one-electron transfer from Ti(III) species to dicyanoalkenes.[4] Dicyanoalkenes (**1b**, **c**, and **e**) which revealed an irreversible reduction behavior on cyclic voltammograms yielded cyclized and uncyclized dimeric products (**2** and **4**). It is clear that the anion radicals produced from **1b**, **c**, and **e** were involved in rapid radical combination reactions to give anions of dimeric intermediates, which underwent either an intramolecular Thorpe reaction to yield aminocyclopentene derivatives **2**, or direct protonation to give hexanedinitrile derivatives **4**.

Interestingly, a reduction product mixture resulted from **1b** at 0 °C, consisting of *trans*-**2b** and *meso*-**4b**; neither *cis*-**2b** nor *dl*-**4b** was obtained. The configurational assignment of *trans*-**2b** was given by the ^{1}H NMR characteristics and the transformation of **2b** to the known *trans*-3,4-diphenylcyclopentanone.[5,6] Because **4b** cyclized upon heating to give *cis*-**2b**, a meso configuration



	R1	R2	R3
1a	H	Ph	Ph
b	Ph	H	CN
c	Ph	Me	CN
d	Ph	Ph	CN
e	Me	Me	CN
f	CN	Ph	Ph

Scheme 1.

Table 1. Reduction of Dicyanoalkenes with Titanium(III) Chloride[a)]

Cyanoalkene	Reaction time	Products and yields/%[b)]				
	h	**2**	**3**	**4**	**5**	Recovered **1**
1a	24	—	—	—	—	100
1b	8	77[c)]	—	16	—	—
1b	8[d)]	86[e)]	—	—	—	—
1c	12	74	—	—	—	21[f)]
1d	20	—	73	—	—	13
1d[g)]	20	—	59	—	31	—[h)]
1e	24	10[i)]	—	—	—	29
1f	8	—	83	—	—	—

a) Reaction conditions: substrate/$TiCl_3$=1/6 (molar), in aqueous THF or DMF (pH 7), at 0°C. b) Isolated yields. c) Trans isomer. d) At 35°C. e) A trans:cis (83:17) mixture. f) A trace amount of 2-phenylethanol was obtained. g) In the presence of benzophenone, see Experimental. h) Diphenylmethanol (63%) was also obtained. i) Other unidentified dimeric products were produced as well.

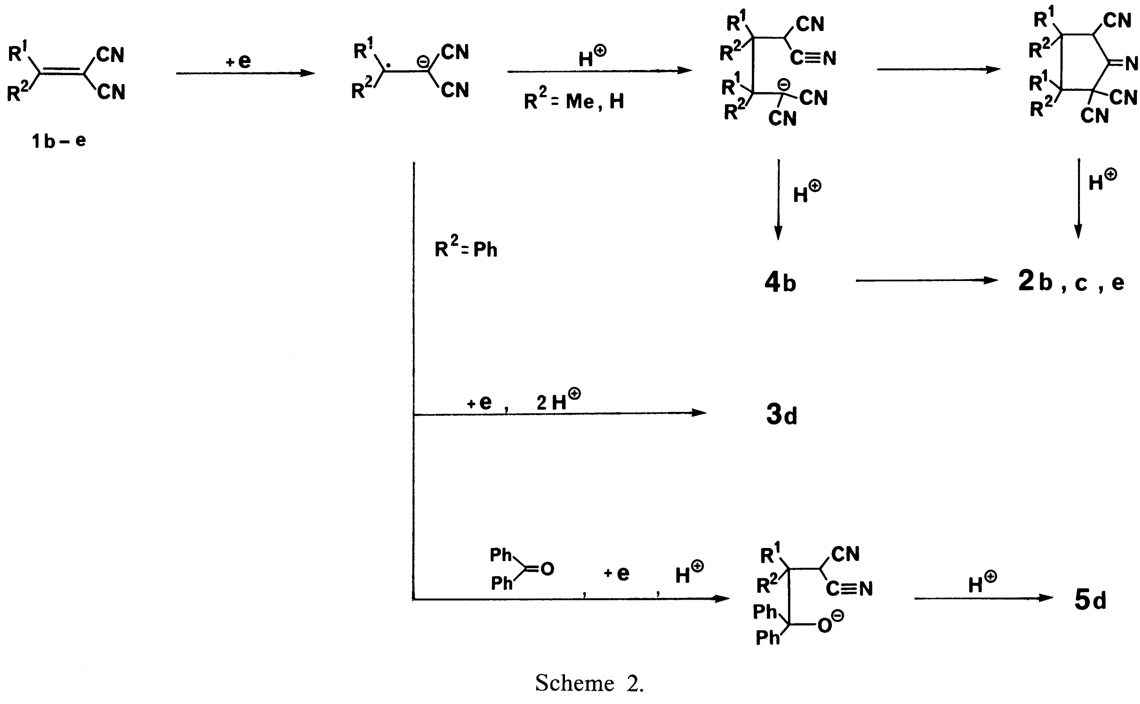
Table 2. Cyclic Voltammetric Parameters of Dicyanoalkenes[a)]

Dicyanoalkene	Peak potentials (V)		Reduction behavior
	1st wave	2nd wave	
1b	−1.43	—	Irrev.[b)]
1c	−1.61	—	Irrev.
1d	−1.45	−1.93	Rev.[c)]
1e	−2.07	—	Irrev.
1f	−1.39	−1.79	Rev.

a) Conditions: 1 mM acetonitrile solution of **1**, Et_4NClO_4 (0.05 M), glassy carbon cathode, Ag/Ag^+ reference electrode, at 25°C. b) Irreversible reduction. c) Reversible reduction.

was assigned to this uncyclized hydrodimer. Thus, the observation that the reduction of **1b** at 35°C yielded a mixture of *trans*- and *cis*-**2b** was rationalized by taking into account the combination of anion radicals to give *dl*- and *meso*-**4b**, and the following Thorpe cyclization to give *trans*- and *cis*-**2b**, respectively, where cyclization of *dl*-**4b** was sterically more amenable. The electrochemical reduction of **1b** was reported to give a 1:1 mixture of *trans*- and *cis*-**2b** through a rapid and conformationaly random combination of the intermediate anion radicals;[7)] in the present reduction, however, the radical combination and following cyclization gave rise to an about 4:1 mixture of *trans*- and *cis*-**2b**. It therefore seems to be highly probable that the anion radicals were held together by Ti(IV) species to keep preferentially in a sterically less congested state (two phenyl groups kept in an anti position); the consequent radical combination afforded predominantly *trans*-**2b**.

In contrast with the reduction products from **1b**, **c**, and **e**, those obtained from **1d** and **f** were monomeric two-



Scheme 2.

electron reduction products (**3**). These dicyanoalkenes (**1d** and **f**) were characterized by the reversible reduction behavior on their cyclic voltammograms. The reduction mechanism of **1d** and **f** should be closely analogous to that which is accepted for the cathodic reduction of alkenes possessing electron withdrawing substituents,[4] i.e., one-electron transfer to the substrates followed by protonation and subsequent electron transfer; the final protonation gives the products. In the presence of added benzophenone, the reduction of **1d** afforded **3d** and a dihydrofuran derivative (**5d**). In this case the anion radical formed from **1d** combined with diphenylketyl radical, which was produced from benzophenone by an electron transfer from Ti(III),[8] to give 3,3-dicyano-1,1,2,2-tetraphenyl-1-propanol which, in turn, afforded **5d** by the following Thorpe-type intramolecular addition. The reduction product obtained from **1f** consisted of solely *dl*-**3f**; no *meso*-**3f** was detected. Hence, a chelating holding of the two cyano groups by Ti(IV) should again be taken into account for this stereoselective reduction process.

Experimental

The melting points were taken on a micro hot-plate melting-point apparatus and are uncorrected. The IR spectra were recorded on a JASCO IRA-3 spectrophotometer. ^{1}H and ^{13}C NMR spectra were determined using a JEOL FX-90Q spectrometer. Chemical shits are given in ppm downfield from internal tetramethylsilane. The mass spectra were recorded on an ESCO EDM-05A spectrometer. The solvents were purified as usual and an aqueous $TiCl_3$ solution was titrated before use.

General Procedure of Titanium(III) Chloride Reduction. A buffered $TiCl_3$ solution was prepared by adding NH_4OAc (5.5 g, 71 mmol) in 25 ml of water to a 1.68 mol dm^{-3} $TiCl_3$ solution (11 ml, 18.5 mmol) under nitrogen. The pH of the solution was adjusted to 7.0 by adding aqueous ammonia. A substituted dicyanoalkene **1** (3 mmol) in 14 ml of THF or DMF was added to the buffered $TiCl_3$ solution; the mixture was then stirred at 0 °C under nitrogen. After the period given in Table 1, the mixture was extracted several times with Et_2O, and the combined extract was washed successively with 5% $NaHCO_3$ solutions, water, and finally with saturated NaCl solutions. The ethereal solution was dried over $MgSO_4$ and the solvent was evaporated under reduced pressure to give a crude product mixture which was separated and purified by silica-gel chromatography.

Reduction of 2-Cyano-3-phenylpropenenitrile (1b). The reduction of **1b** (467 mg, 3 mmol) was carried out for 8 h; the mixture was then filtered. The solid matter was washed with 2 M HCl (1 M=1 mol dm^{-3}) and water. The combined washings were neutralized and combined with the initial filtrate, and all of the solutions were extracted several times with Et_2O. The ethereal solution was washed with water and dried over $MgSO_4$; the solvent was evaporated under reduced pressure to give a crude product mixture. This was combined with the above-mentioned acid-washed solid, and the mixture was separated on a silica-gel column (eluent; $CHCl_3$) to give *trans*-1-amino-2,5,5-tricyano-3,4-diphenyl-1-cyclopentene (*trans*-**2b**, 77%) and *meso*-2,5-dicyano-3,4-diphenylhexanedinitrile (*meso*-**4b**, 16%). The reaction at 35 °C gave a trans : cis (87 : 13) mixture of **2b** (86%) after usual work up. Upon heating an acetone solution of *meso*-**4b** for 8 h, the corresponding cyclized product, *cis*-**2b**, was obtained in 48% yield.

***trans*-2b:** Mp 180.5—181.0 °C; IR (KBr) 3410, 3320 (NH), 2200 (CN), and 1665 (C=C) cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=3.73 (1H, d, J=8.6 Hz, H_4), 4.83 (1H, d, J=8.6 Hz, H_3), 5.61 (2H, br, NH_2), 7.14 (5H, s, Ph), and 7.28 (5H, s, Ph); ^{13}C NMR ($CDCl_3$) δ=47.8 (C_5), 51.3 (C_4), 63.3 (C_3), 84.1 (C_2), 110.9, 112.3, and 115.0 (CN×3), 127.5, 128.5, 128.9, 129.1, 129.3, 129.8, 131.3, 137.1 (Ph), and 149.7 (C_1); MS m/z 310 (M^+), 309, and 153. Found: C, 77.29; H, 4.57; N, 17.94%. Calcd for $C_{20}H_{14}N_4$: C, 77.40; H, 4.55; N, 18.05%.

***cis*-2b:** Mp 160.2—161.0 °C; ^{1}H NMR ($CDCl_3$) δ=4.26 (1H, d, J=7.6 Hz, H_4), 4.50 (1H, d, J=7.6 Hz, H_3), 5.41 (2H, br, NH_2), and 6.74—7.30 (10H, m, Ph).

***meso*-4b:** Mp 228 °C (decomp); IR (KBr) 2260 (CN) cm^{-1}; ^{1}H NMR (DMSO) δ=4.17—4.30 (2H, m, CHPh), 4.45—4.58 (2H, m, $CH(CN)_2$), and 7.42—7.80 (10H, m, Ph); ^{13}C NMR (DMSO) δ=28.9 (C_2 and C_5), 45.5 (C_3 and C_4), 112.1 and 112.5 (CN×2), 128.7, 129.2, 129.5, and 134.2 (Ph); MS m/z 310 (M^+), 180, 155, and 129. Found: C, 77.34; H, 4.64; N, 18.32%. Calcd for $C_{20}H_{14}N_4$: C, 77.40; H, 4.55; N, 18.05%.

Hydrolysis of *trans*-2b. Phosphoric acid (20 ml) was added to a solution of *trans*-**2b** (1.0 g in 30 ml of AcOH and 3 ml of water) and the mixture was refluxed overnight. The mixture was poured into ice-water (200 ml) and stirred for 30 min. The precipitates were collected by filtration and recrystallized from ethanol to give *trans*-3,4-diphenylcyclopentanone almost quantitatively; mp 178.0—179.0 °C (lit,[5,6] mp 177—179 °C); IR (KBr) 1745 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=2.3—3.1 (4H, m), 3.3—3.7 (2H, m), and 7.0—7.4 (10H, m); MS m/z 236 (M^+) and 103.

Reduction of 2-Cyano-3-phenyl-2-butenenitrile (1c). The reduction of **1c** (509 mg, 3.0 mmol) was carried out for 12 h; the product was then chromatographed (eluent; PhH) to give **1c** (21%), 1-amino-2,5,5-tricyano-3,4-dimethyl-3,4-diphenyl-1-cyclopentene (**2c**, 74%, as a 1 : 1 trans : cis mixture), and a trace amount of acetophenone and 1-phenylethanol.

2c: Mp 181—195 °C; IR (KBr) 3410, 3330 (NH), 2190 (CN), 1665 (C=C) cm^{-1}; ^{1}H NMR ($CDCl_3$) *trans*-**2c** δ=1.90 (3H, s, Me), 2.00 (3H, s, Me), 5.43 (2H, br, NH_2), and 6.81 (10H, m, Ph); *cis*-**2c** δ=1.23 (3H, s, Me), 1.43 (3H, s, Me), 5.43 (2H, br, NH_2), and 7.26 (10H, m, Ph); MS m/z 338 (M^+), 170, and 168. Found: C, 77.95; H, 5.32; N, 16.59%. Calcd for $C_{22}H_{18}N_4$: C, 78.08; H, 5.36; N, 16.56%.

Reduction of 2-Cyano-3,3-diphenylpropenenitrile (1d). The reduction of **1d** (352 mg, 1.5 mmol) was carried out for 20 h to give 2-cyano-3,3-diphenylpropanenitrile (**3d**, 73%) and **1d** (13%). A similar reaction of **1d** (251 mg, 1.1 mmol) in the presence of benzophenone (200 mg, 1.1 mmol) gave **3d** (59%), 5-amino-4-cyano-2,2,3,3-tetraphenyl-2,3-dihydrofuran (**5d**, 31%), and diphenylmethanol (63%) after chromatography (eluent; Hexane–AcOEt).

3d: Mp 84.8—85.6 °C (lit,[7,9] mp 80—82 °C); IR (KBr) 2930 and 2180 (CN) cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=4.25 (1H, d, J=7.6 Hz, Ph_2CH), 4.55 (1H, d, J=7.6 Hz, $HC(CN)_2$), and 7.2 (10H, m, Ph); MS m/z 232 (M^+) and 167.

5d: Mp 214.2—214.8 °C; IR (KBr) 3470, 3320 (NH), 2285 (CN), and 1660 (C=C) cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=5.18 (2H, br, NH_2) and 7.0 (20H, m, Ph); MS m/z 414 (M^+) and 371.

Found: C, 83.96; H, 5.30; N, 6.73%. Calcd for $C_{29}H_{22}ON_2$: C, 84.03; H, 5.35; N, 6.76%.

Hydrolysis of 5d. The hydrolysis of **5d** was achieved by the procedure described for that of **2b** and gave 2-cyano-3,3,4,4-tetraphenyl-4-butanolide (83%): Mp 266.2—267.0 °C; IR (KBr) 2250 (CN) and 1790 (CO) cm^{-1}; ^{1}H NMR (CDCl$_3$) δ=4.9 (1H, s, CH) and 6.5—7.6 (20H, m, Ph); MS *m*/*z* 205 and 105. Found: C, 83.89; H, 5.09; N, 3.40%. Calcd for $C_{29}H_{21}O_2N$: C, 83.83; H, 5.09; N, 3.37%.

Reduction of 2-Cyano-3-methyl-2-butenenitrile (1e). The reduction of **1e** (653 mg, 6.1 mmol) was carried out for 24 h to give 1-amino-2,5,5-tricyano-3,3,4,4-tetramethyl-1-cyclopentene (**2e**, 10%), **1e** (29%), and unidentified dimeric products after chromatography (eluent; PhH–AcOEt).

2e: Mp 182.0—182.6 °C: IR (KBr) 3417, 3366, 2193 (CN), 1666 (C=C) cm^{-1}, ^{1}H NMR (CDCl$_3$) δ=1.33 (6H, s, Me), 1.20 (6H, s, Me), and 4.92 (2H, br, NH$_2$); MS *m*/*z* 214 (M$^+$), 158, and 159. Found: C, 67.28; H, 6.67; N, 26.06%. Calcd for $C_{12}H_{14}N_4$: C, 67.26; H, 6.59; N, 26.15%.

Reduction of 2,3-Diphenyl-2-butenedinitrile (1f). The reduction of **1f** (348 mg, 1.5 mmol) was carried out for 8 h as described before. The precipitated solid was collected by filtration; the filtrate was then worked up as usual to give a crude solid. The combined solid mass was chromatographed (eluent; PhH) to give *dl*-1,2-dicyano-1,2-diphenylethane (**3f**, 83%).

***dl*-3f:** Mp 164.4—165.2 °C (lit,[10] mp 160 °C); IR (KBr) 2240 (CN) cm^{-1}; ^{1}H NMR (CDCl$_3$) δ=4.17 (2H, s) and 7.01—7.35 (10H, m); MS *m*/*z* 232 (M$^+$) and 115.

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References

1) E. J. McMurry, *Acc. Chem. Res.*, **7**, 281 (1974).

2) A. Sera, S. Fukumoto, M. Tamura, K. Takabatake, H. Yamada, and K. Itoh, *Bull. Chem. Soc. Jpn.*, **64**, 1787 (1991).

3) A. Clerici and O. Porta, *Tetrahedron,* **38**, 1293 (1982).

4) L. A. Avaca and J. H. P. Utley, *J. Chem. Soc., Perkin 2,* **1975**, 161.

5) J. W. Lynn and J. English, Jr., *J. Org. Chem.*, **16**, 1546 (1951).

6) P. T. Lansbury, E. J. Nienhouse, D. J. Scharf, and F. R. Hilfiker, *J. Am. Chem. Soc.*, **92**, 5649 (1970).

7) L. A. Avaca and J. H. P. Utley, *J. Chem. Soc., Perkin 2,* **1975**, 971.

8) A. Clerici, O. Porta, and P. Zago, *Tetrahedron,* **42**, 561 (1986).

9) E. Campaigne and W. L. Roelofs, *J. Org. Chem.*, **30**, 396 (1965).

10) D. G. Coe, M. M. Gale, R. P. Linstead, and C. J. Timmons, *J. Chem. Soc.*, **1957**, 123.