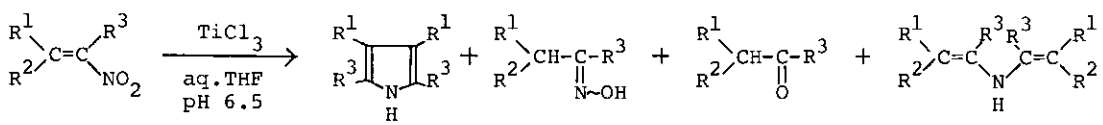
TITANIUM TRICHLORIDE MEDIATED REDUCTION OF NITROSTYRENES

Akira Sera*, Shoji Fukumoto, Takako Yoneda, and Hiroaki Yamada
Department of Chemistry, Faculty of Science, Kobe University,
Nada-ku, Kobe 657, Japan

Abstract —— Reactions of substituted nitrostyrenes with aqueous titanium trichloride afforded pyrroles, carbonyl compounds, and oximes. In some instances, divinylamines were produced as well. The reaction mechanism is rationalized taking account of electron transfer to nitroethylenes from Ti(III), followed by protonation, dimerization, cyclization, and hydrolysis.

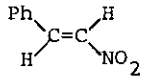
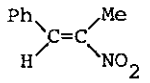
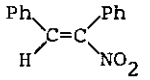
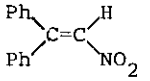
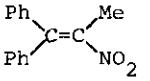
Recently synthetic utility of titanium trichloride as a deoxygenating reagent for N-O functionalities has begun appearing in literatures. Thus nitroalkanes and their derivatives were reported to give the corresponding carbonyl compounds,[1] where the intervention of imine intermediates was suggested. Reduction of nitroarenes by aqueous titanium trichloride also afforded anilines in good yields.[2,3] However, reactions of nitroolefins with titanium trichloride has received little attention.[4] We describe here that the reduction (electron transfer-protonation) of nitrostyrene derivatives 1 has been achieved by aqueous titanium trichloride under mild conditions to give pyrroles 2, besides the corresponding oximes 3, and carbonyl compounds 4. In some cases, a concurrent formation of divinylamines 5 was observed. The product distributions seem to be governed mainly by an extent of steric overcrowding around the radical center of intermediate anion radicals 6 (Scheme 2).



1 2 3 4 5

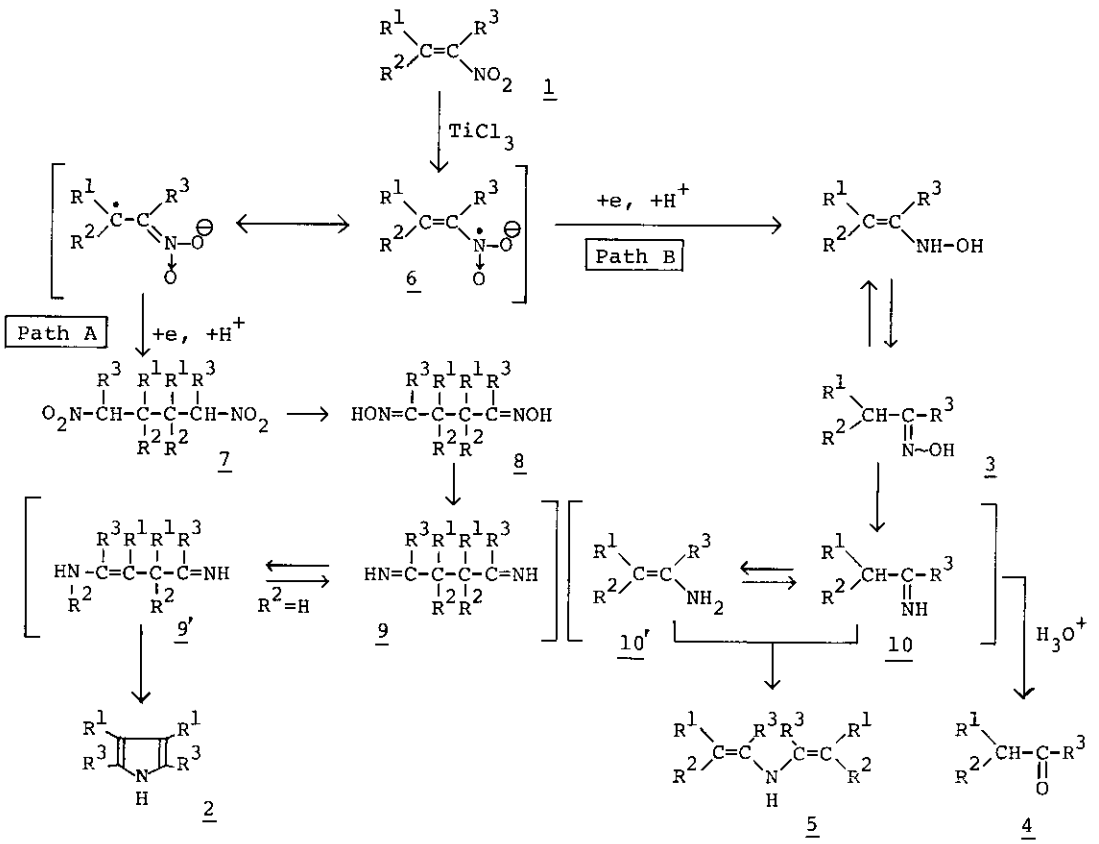
Scheme 1.

Table. Reaction of Nitrostyrenes with Titanium Trichloride[a)]

Nitrostyrene	Reaction time / h / temp. / °C	Molar ratio $TiCl_3$ / 1	Yield of products / %				
			Pyrrole 2	Oxime 3	Carbonyl compound 4	Divinylamine 5	Others
1a 	0.5/0	6	3	0	0	0	7a 6 [f)]
	24/35	12	26	0	0	0	
1b 	0.5/0	6	6	0	35	0	8b 7
	24/35	12	32	0	60	0	
1c 	1.5/0	6	0	6	62	0	
	24/35	12	20	38	0	0	
1d 	4/0	6	0	46	15	32	
	0.5/30	6	0	19	22	50	
	0.5/30[b)]	6	0	16	12	42	
	0.5/30[c)]	6	0	0	46	17	
	0.5/30[d)]	6	0	0	53	11	
1e 	20/0	6	0	56	27	0	
	24/35	12	0	0	84	14[e)]	

a) The reactions were carried out in aqueous THF (pH 6.5, ammonium acetate buffer) and continued untill all the nitrostyrene has been consumed out. b) At pH 6.0. c) At pH 2.0. d) At pH < 1. e) A divinylamine structure was inferred from NMR and IR data. f) A small amount of oil (structure unidentified) was also obtained.

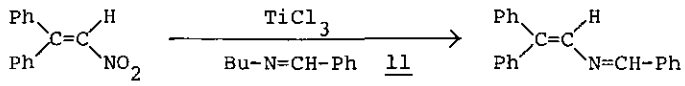
Treatment of 2-phenyl-1-nitroethylene 1a with aqueous titanium trichloride at pH 6.5[5] afforded 3,4-diphenylpyrrole 2a and a dinitro dimer 7a. The yield of the pyrrole considerably increased under the prolonged reaction time at higher temperatures. Formation of the pyrrole is considered to arise from electron transfer from Ti(III) to the nitroolefin 1a to give a resonance stabilized anion radical 6a. This anion radical, being sterically less hindered at C-2 as compared with 6d and 6e, easily dimerizes to give a dinitro dimer 7a. Successive electron transfer and protonation produce an enaminoimine intermediate 9'a, which gives rise to 3,4-diphenylpyrrole 2a by a subsequent intramolecular addition-elimination. A similar reaction sequence is responsible for the formation of a dioxime 8b and 2,5-dimethyl-3,4-diphenylpyrrole 2b from 1-nitro-1-methyl-2-phenylethylene 1b, and also



Scheme 2.

for the formation of 2,3,4,5-tetraphenylpyrrole 2c from 1-nitro-1,2-diphenylethylene 1c. When 2,2-diphenylnitroolefins 1d,e were employed, divinylamines 5d,e were obtained in a considerable amount. Lowering the pH was found to decrease the yield of 5. The divinylamines are characterized as a sort of "cross-conjugated dienamines (an open chain version of pyrroles)".[7] Cross conjugated dienamines have been described in literatures.[6] However, the dienamines of the type C=C-N-C=C have been little documented,[7,8] although many of those having C=C-C=C-N or C=C-C(N)=C functionalities have been synthesized and their characteristics are elucidated thoroughly.[6] Unexpected formation of these dienamines 5d,e may arise from the electron transfer from Ti(III) to nitroolefins to give anion radicals 6d,e, in which the radical center C-2 no longer possesses dimerizing ability because of overcrowding brought about by two phenyl groups. Thus the reaction prefers to go through path B rather than path A, giving rise to oximes 3d,e and then imine intermediates 10d,e, which tautomerizes into vinylamines 10'd,e. The imines 10d,e

yield either carbonyl compounds 4d,e by hydrolysis or cross-conjugated dienamines 5d,e by being nucleophilically attacked by 10'd,e followed by elimination of ammonia (Scheme 2).[9] Intervention of vinylamines 10'd,e was proven by an experimental observation that the reaction of 1d with titanium trichloride in the presence of N-benzylidenebutylamine 11 afforded N-benzylidene-2,2-diphenylvinylamine 12 in 40% yield (Scheme 3).



1d 12

Scheme 3.

The anion radical 6c from nitrodiphenylethylene 1c may afford ketimine intermediate 10c, in which, however, 1-phenyl group possibly stabilizes the imine structure. Consequently, the ketimine does not tend to isomerize to the vinylamine counterpart, hence no cross-conjugated dienamine is yielded.

EXPERIMENTAL

(1) Reduction of Nitrostyrenes with $TiCl_3$ at 0°C.

A buffered $TiCl_3$ solution was prepared by adding NH_4OAc (5.5 g, 71 mmol) in 25 ml of H_2O to 1.76 M aqueous $TiCl_3$ (11 ml) under nitrogen. Adjustment of pH was done by adding 10 w/v % aqueous NH_4OH to the solution. Nitrostyrene (3 mmol) in 14 ml of THF was added rapidly and the stirring was continued at 0°C under nitrogen for the indicated period, after which time the consumption of nitrostyrene was complete (monitored by TLC method). The reaction mixture was extracted several times with ether. The organic extracts were combined, washed with aqueous $NaHCO_3$, H_2O, and with brine, then dried ($MgSO_4$). The ether solution was concentrated under vacuum. The residue was subjected to silica gel column chromatography separation.

(2) Reduction of Nitrostyrenes with $TiCl_3$ at 35°C.

A buffered $TiCl_3$ solution was prepared from 11 g of NH_4OAc in 25 ml of H_2O, 22 ml of 1.76 M aqueous $TiCl_3$, and aqueous NH_4OH. Nitrostyrene (3 mmol) in 24 ml of THF was added and the mixture was stirred for the indicated period. The reaction mixture was worked up as in procedure (1).

(3) Reduction of 1,1-Diphenyl-2-nitroethylene 1d in the presence of N-benzylidenebutylamine 11.

To a buffered $TiCl_3$ solution prepared as in procedure (1), 1,1-diphenyl-2-nitroethylene (3 mmol) and N-benzylidenebutylamine (15 mmol) in 14 ml of THF was added under nitrogen. The mixture was stirred for 1 hr at 30°C. The reaction mixture was then extracted with ether. The extract was washed with aqueous $NaHCO_3$, H_2O, and with brine, then dried ($MgSO_4$). The ether was removed in vacuo to yield crude 1,4,4-triphenyl-2-azabutadiene. Recrystallization from EtOH gave 340 mg of pure azabutadiene 12 (40% yield).

1a: mp 57.2-57.5°C (ethanol). ^{1}H-NMR (CCl_4) δ 7.3 (5H, s, PhH), 7.3 (1H, d, J= 14 Hz, CH), 7.8 (1H, d, J=14 Hz, CH).

1b: mp 149.2-150.3°C (ethanol). ^{1}H-NMR ($CDCl_3$) δ 2.4 (3H, s, CH_3), 7.3 (5H, s, PhH), 7.9 (1H, s, CH).

1c: mp 73.0-74.5°C (hexane/benzene). H^1-NMR ($CDCl_3$) δ 7.2 (10H, m, PhH), 8.1 (1H, s, CH).

1d: mp 86.2-86.5°C (ethanol). ^{1}H-NMR ($CDCl_3$) δ 7.1 (10H, m, PhH), 7.2 (1H, s, CH).

1e: mp 56.3-56.7°C(ethanol). ^{1}H-NMR ($CDCl_3$) δ 2.3 (3H, s, CH_3), 7.1 (10H, m, PhH).

2a: oil. ^{1}H-NMR (CCl_4) δ 6.7 (2H, d, J=2.6 Hz, 2,5-CH), 7.1 (10H, m, PhH), 8.0 (1H, b, NH). IR (neat) 3400 cm^{-1} (NH). MS m/z 219 (M^+), 189, 104, 77.

2b: mp 145-148°C (benzene/hexane). ^{1}H-NMR ($CDCl_3$) δ 2.2 (6H, s, CH_3), 7.0 (10H, m, PhH), 7.3 (1H, b, NH). MS m/z 247 (M^+), 230, 179, 105, 77.

2c: mp 213.5-214.2°C (benzene/hexane). ^{1}H-NMR ($CDCl_3$) δ 6.8-7.4 (20H, m, PhH), 8.2 (1H, b, NH). MS m/z 371 (M^+), 298.

3c: mp 86.0-89.0°C (ethanol). ^{1}H-NMR ($CDCl_3$) δ 4.1 (2H, s, CH_2), 6.5-7.7 (10H, m, PhH), 9.3 (1H, b, OH). IR (KBr) 3200 cm^{-1} (OH). MS m/z 211 (M^+), 193, 91, 77.

3d: oil (1:1 mixture of syn- and anti-isomer). ^{1}H-NMR ($CDCl_3$) δ 4.8 (1H, d, J= 8 Hz, Ph_2CH), 5.6 (1H, d, J=8 Hz, Ph_2CH), 6.7-7.3 (21H, m, PhH, N=CH), 7.6 (1H, d, J=8 Hz, N=CH), 8.5 (2H, b, OH).

3e: mp 160-162°C (ethanol). ^{1}H-NMR ($CDCl_3$) δ 1.8 (3H, s, CH_3), 4.9(1H, s, Ph_2CH), 7.1 (10H, m, PhH), 8.5 (1H, s, OH). IR (KBr) 3600-2800 cm^{-1} (OH). MS m/z 225 (M^+), 208, 193, 167, 165, 152.

4b: bp 77.5°C/6 mm Hg. ^{1}H-NMR ($CDCl_3$) δ 2.0 (3H, s, CH_3), 3.5 (2H, s, CH_2), 7.1 (5H, m, PhH). IR (neat) 1720 cm^{-1}(C=O). MS m/z 134 (M^+), 122, 105, 91, 77.

4c: mp 53.9-54.2°C (ethanol). ^{1}H-NMR ($CDCl_3$) δ 4.2 (2H, s, CH_2), 7.0-8.0 (10H, m, PhH). IR (KBr) 1680 cm^{-1} (C=O). MS m/z 196 (M^+), 105, 91, 77.

4d: oil. ^{1}H-NMR ($CDCl_3$), δ 4.7 (1H, d, J=2.4 Hz, Ph_2CH), 7.1 (10H, m, PhH), 9.6 (1H, d, J=2.4 Hz, CHO). IR (neat) 2780, 2680, 1720 cm^{-1} (CHO).

4e: mp 53.8-54.0°C (ethanol). ^{1}H-NMR ($CDCl_3$) δ 2.1 (3H, s, CH_3), 5.0 (1H, s, CH), 7.1 (10H, m, PhH). IR (KBr) 1710 cm^{-1} (C=O). MS m/z 210 (M^+), 167, 165, 152.

5d: mp 143.5-144.5°C (benzene/hexane). ^{1}H-NMR ($CDCl_3$) δ 6.6 (2H, s, CH), 7.0 (21H, m, PhH, NH). IR (KBr) 3360, 3200 cm^{-1} (NH). MS m/z 373 (M^+), 296, 206, 178, 77.

5e: oil. ^{1}H-NMR ($CDCl_3$) δ 2.2 (6H, s, CH_3), 6.8-7.7 (21H, m, PhH, NH). IR (neat) 3400 cm^{-1} (NH).

7a: mp 178-180°C. ^{1}H-NMR (DMSO-d_6) δ 3.5-5.2 (6H, m, PhCH-CH_2), 7.3 (10H, m, PhH). IR (KBr) 1550, 1380 cm^{-1} (NO_2). MS m/z 300 (M^+), 284, 150, 134, 104, 91, 77.

8b: mp 370°C, dec. ^{1}H-NMR (DMSO-d_6) δ 1.5 (6H, s, CH_3), 4.2 (2H, s, CH), 7.0 (10H, m, PhH), 9.7 (2H, s, OH). IR (KBr) 3240 cm^{-1} (OH). MS m/z 296 (M^+), 279, 148.

12: mp 131.5-133.5°C (ethanol). ^{1}H-NMR ($CDCl_3$) δ 7.0-7.7 (16H, m, PhH, CH=), 8.3 (1H, s, CH-Ph). IR (KBr) 1620 cm^{-1} (C=N). MS m/z 283 (M^+), 206, 178.

ACKNOWLEDGEMENTS

This work was supported partly by Grant-in-Aid for Scientific Research (No.60430008) from the Ministry of Education, Japan.

REFERENCES

1. J. E. McMurry and J. Melton, J. Org. Chem., 1973, 38, 4367.
2. T. -L. Ho and C. M. Wong, Synthesis, 1974, 44.
3. M. Somei, K. Kato, and S. Inoue, Chem. Pharm. Bull., 1980, 28, 2515.
4. The sole reported example is the reaction of 1-nitrocyclooctene with titanium trichloride under acidic conditions, to yield cyclooctanone.[1]
5. For reaction conditions, see Table footnote.
6. 'Enamines: Synthesis, Structure, and Reactions', ed. by A. G. Cook, Dekker, New York 1969.
7. B. Witkop, J. Am. Chem. Soc., 1965, 78, 2873.
8. T. Zaima, Y. Matsunaga, and K. Mitsuhashi, J. Heterocycl. Chem., 1983, 20, 1.
9. Witkop[7] has synthesized the same dienamine 5d from 2,2-diphenylacetaldehyde and ammonia, and proposed a similar mechanism.

Received, 20th September, 1985