Anodic Oxidation of *o*-Nitrophenylthioiminocycloalkanes

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Two-electron anodic oxidation of *o*-nitrophenylthioiminocyclopentane (1) in methanol, followed by nucleophilic attacks of solvent and water (the latter present as an impurity in the solvent), gave methyl sulfinate and cyclopentaneimine. On the other hand, one-electron oxidation of *o*-nitrophenylthioiminocycloalkanes (1—6) in acetonitrile followed by deprotonation of the cation radical (B) gave the neutral radical (C), which then gave the thiyl radical (E). The rest of C reacted with E to give *N*,2-bis(*o*-nitrophenylthio)iminocycloalkanes, whose oxidation gave the final products (9—14). The results of cyclic voltammetry of 1—6 also show that the initial steps of anodic oxidation of 1—6 in acetonitrile and in methanol are one- and two-electron oxidations, respectively.

Keywords anodic oxidation; substituted thio-oxime; methyl 2-nitrobenzenesulfinate; cyclic voltammetry; nitrene

There are some organic sulfur species whose reactivities are still unknown in spite of great efforts by many chemists.[1] *o*-Nitrophenylthioiminocycloalkanes are one of such species.[2] Their anodic oxidation is expected to involve a unique mechanism, because the molecules contain divalent sulfur linked, with trivalent nitrogen, and such a chemical bond in sulfenamides[3,4] gave several kinds of reactive intermediates. The aim of this study was to elucidate the mechanism of oxidation of *o*-nitrophenylthio-oximes (**1**—**6**).

Results and Discussion

Controlled potential electrolysis (CPE) of *o*-nitrophenylthioiminocycloalkanes (**1**—**6**) in acetonitrile solution containing 0.1 M $NaClO_4$ as a supporting electrolyte at 1.40—1.44 V *vs.* a saturated calomel electrode (S.C.E.) gave the results summarized in Table I.

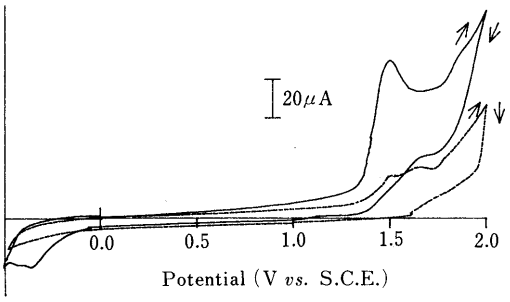

Fig. 1. Cyclic Voltammograms of 2 mM *o*-Nitrophenylthioiminocyclopentane (**1**)

The supporting electrolyte was 0.1 M $NaClO_4$. Glassy carbon anode; scan rate, 50 mV/s; at 25 °C. ——, in methanol; ------, in acetonitrile.

On the other hand, CPE of **1** in methanol solution at 1.44 V gave methyl 2-nitrobenzenesulfinate (**7**) and cyclopentanone (**8**) as the final products. The yields of **7** and **8** were 63.6 and 57.5%, respectively, and the *n*-value was 2.2. The cyclic voltammograms of **1** in methanol and in acetonitrile are shown in Fig. 1.

The fact that the i_p value of the first anodic peak of **1** in methanol is *ca.* 3 times larger than that in acetonitrile suggests that the initial step of anodic oxidation of **1** in methanol is a two-electron transfer process, whereas that of **1** in acetonitrile is a one-electron transfer process.[5] The *n*-values of CPE of **1** in methanol and in acetonitrile support this hypothesis. The following scheme is suggested for the anodic oxidation of **1** in methanol.

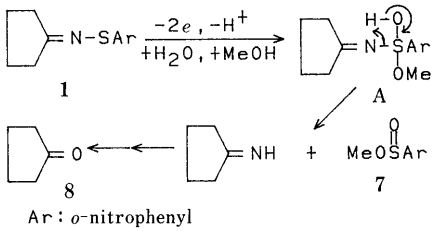

Chart 1

TABLE I. Results of Controlled Potential Electrolysis of *o*-Nitrophenylthioiminocycloalkanes (10 mM) in Acetonitrile at a Glassy Carbon Anode

Compd. No.	Phenylthioimino-cycloalkanes	Applied potential V *vs.* S.C.E.	*n*-Value	Products identified (Compd. No.)	Yields (%)
1	RS–N=cyclo-C_5H_8	1.44	0.57	*N*,2,2-Tris(*o*-nitrohenylthio)iminocyclopentane (**9**)	26.7
				o,*o*′-Dinitrodiphenyldisulfide	11.3
				Cyclopentanone (**8**)	20.0
2	RS–N=cyclo-C_6H_{10}	1.40	0.75	*N*,2-Bis(*o*-nitrophenylthio)iminocyclohex-2-ene (**10**)	18.3
				o,*o*′-Dinitrodiphenyldisulfide	7.3
3	RS–N=cyclo-C_6H_9–2-Me	1.44	0.66	2-Methyl-*N*,2-bis(*o*-nitrophenylthio)iminocyclohexane (**11**)	10.8
				o,*o*′-Dinitrodiphenyldisulfide	Trace
4	RS–N=cyclo-C_6H_9–3-Me	1.44	0.66	5-Methyl-*N*,2-bis(*o*-nitrophenylthio)iminocyclohex-2-ene (**12**)	8.8
				o,*o*′-Dinitrodiphenyldisulfide	14.7
5	RS–N=cyclo-C_6H_9–4-Me	1.40	0.70	4-Methyl-*N*,2-bis(*o*-nitrophenylthio)iminocyclohex-2-ene (**13**)	12.5
				o,*o*′-Dinitrodiphenyldisulfide	6.7
6	RS–N=cyclo-C_7H_{12}	1.44	0.59	*N*2,2-Tris(*o*-nitrophenylthio)iminocycloheptane (**14**)	28.0

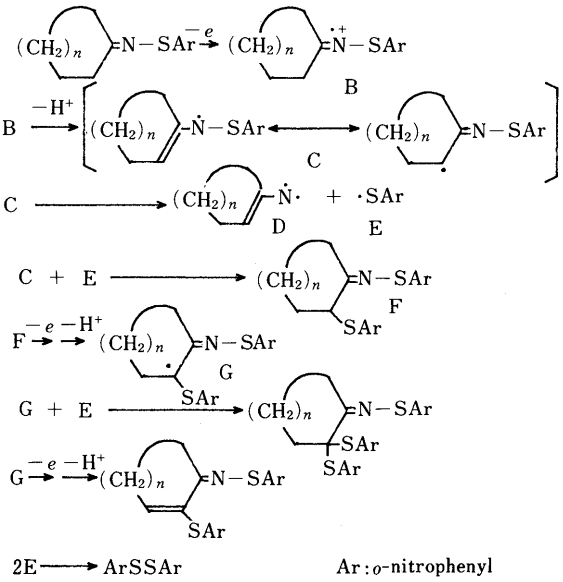

Chart 2

Two-electron oxidation of **1** is followed by nucleophilic attacks of solvent and water, the latter of which is present in a small amount (*ca.* 5.6 mM) as an impurity in the solvent. The concerted S–N bond cleavage with proton migration from oxygen to nitrogen in A gives methyl sulfinate and cyclopentylimine. Hydrolysis of the latter gives **8** as a final product.

The anodic oxidation mechanism of **1**—**6** in acetonitrile is far more complicated, but the processes shown in Chart 2 are consistent with the experimental results.

The cation radical (B) is generated by a one-electron oxidation of **1**—**6** in acetonitrile and the deprotonation of B gives the neutral radical (C). A part of C gives the nitrene (D) and thiyl radical (E) just as neutral radicals are generated by the oxidation of sulfenamides in benzene.[6] Dimerization of E leads to the disulfide, and the reaction of E with C gives *N*,2-bis(*o*-nitrophenylthio)iminocycloalkane (F), which then gives another neutral radical (G) by anodic oxidation, followed by deprotonation except in the case of **11**, which was not electrolyzed. Because the unpaired electron in G is located on the carbon atom involved in the S–C bond in the cycloalkane ring, **9** and **14** instead of *N*,2,6-tris(*o*-nitrophenylthio)iminocycloalkanes were given by the reaction of E with G. The nitrene (D), which is one of the most reactive intermediates[7] will consume a part of **1**—**6** by electrophilic attack and this may be a reason why the *n*-value is less than unity. The hydrogen abstraction reaction followed by hydrolysis transforms D into cyclopentaneimine, which is detected as one of final products, that is **8**.

When G is electrolyzed instead of being attacked by E, *N*,2-bis(*o*-nitrophenylthio)iminocycloalkenes, which were **10**, **12** and **13**, are formed.

It is still unknown what factors determine the distribution of final products in the oxidation of **1**—**6**.

Experimental

Materials Thio-oximes were prepared by refluxing a benzene solution of *o*-nitrobenzenesulfenamide with the corresponding cycloketones[4] in the presence of a catalytic amount of benzenesulfonic acid, and purified by column chromatography on alumina with benzene as an eluant, followed by recrystallization from methanol. Each compound gave analysis results consistent with theoretical values. Acetonitrile was purified as described previously.[6] Methanol was dried with activated magnesium and distilled.

Apparatus Cyclic voltammetry and controlled potential electrolysis were carried out as described previously.[8] All potentials were measured against a saturated calomel electrode. Infrared (IR), nuclear magnetic resonance (NMR) and mass spectra were obtained as described previously.[8]

Isolation of Products from Controlled Potential Electrolysis of Thio-oximes Typical examples of the procedure are given below. Other compounds were obtained by essentially the same procedure.

Isolation of *N*,2,2-Tris(*o*-nitrophenylthio)iminocyclopentane (9) Compound **1** (236.7 mg) was subjected to electrolysis in acetonitrile (100 ml) containing 0.1 M $NaClO_4$ at 1.44 V at room temperature. The quantity of electricity consumed (55.0 C) corresponded to $n=0.57$. The solution from electrolysis was concentrated to half the initial volume, added to 100 ml of saturated aqueous NaCl solution, and then extracted with 150 ml of benzene. The organic solution was dried with Na_2SO_4 and concentrated to dryness and the residue was subjected to column chromatography on silica gel with benzene as an eluent. The product (17.2 mg) obtained from the first fraction was identified as *o*,*o*'-dinitrodiphenyldisulfide by comparison of its IR spectrum with that of an authentic sample. The product (47.6 mg) obtained from the second fraction was identified as **9** on the basis of elemental analysis data, and IR, NMR, and mass spectra, mp 172—172.5 °C (recrystallized from ethyl acetate). *Anal.* Calcd for $C_{23}H_{18}N_4O_6S_3$: C, 50.91; H, 3.34; N, 10.32. Found: C, 50.77; H, 3.20; N, 10.19. IR ν_{max}^{KBr} cm^{-1}: 1510 (NO_2), 1345 (NO_2). ^{1}H-NMR ($CDCl_3$) δ: 2.18 (2H, m, CH_2), 2.34 (2H, t, CH_2), 2.67 (2H, t, CH_2), 7.27 (1H, t, aromatic proton), 7.35 (2H, t, aromatic protons), 7.51 (3H, t, aromatic protons), 7.69 (1H, d, aromatic proton), 7.76 (2H, d, aromatic protons), 8.08 (2H, d, aromatic protons), 8.26 (1H, d, aromatic proton). MS *m/z*: 154 ($O_2NC_6H_4S^+$).

Isolation of Methyl *o*-Nitrobenzenesulfinate (7) Compound **1** (239.1 mg) was subjected to electrolysis in methanol (100 ml) containing 0.1 M $NaClO_4$ at 1.44 V at room temperature. The quantity of electricity consumed (215.7 C) corresponded to $n=2.2$. The solution from electrolysis was treated as described above except that alumina was used for column chromatography instead of silica gel. The product, obtained by evaporation of the appropriate fraction under reduced pressure, was identified as **7** on the basis of IR, NMR and mass spectra and melting point (58—59 °C, lit. 55—57 °C[9]), IR ν_{max}^{KBr} cm^{-1}: 1520 (NO_2), 1340 (NO_2), 1122 (S=O). ^{1}H-NMR ($CDCl_3$) δ: 3.52 (3H, s, OCH_3), 7.61 (1H, t, aromatic proton), 7.76 (1H, t, aromatic proton), 8.07 (1H, d, aromatic proton), 8.08 (1H, d, aromatic proton). MS *m/z*: 202 ($M^+ + 1$), 170 ($O_2NC_6H_4S^+O$).

N,2-Bis(*o*-nitrophenylthio)iminocyclohex-2-ene (**10**): mp 180.5—182 °C (recrystallized from ethyl acetate). *Anal.* Calcd for $C_{18}H_{15}N_3O_4S_2$: C, 53.85; H, 3.76; N, 10.46. Found: C, 53.71; H, 3.69; N, 10.32. IR ν_{max}^{KBr} cm^{-1}: 1510 (NO_2), 1340 (NO_2). ^{1}H-NMR ($CDCl_3$) δ: 2.10 (2H, m, CH_2), 2.56 (2H, q, CH_2), 2.85 (2H, t, CH_2), 7.1—7.4 (5H, m, aromatic protons), 7.61 (1H, d, aromatic proton), 8.15 (1H, d, aromatic proton), 8.18 (1H, d, aromatic proton). MS *m/z*: 154 ($O_2NC_6H_4S^+$).

2-Methyl-*N*,2-bis(*o*-nitrophenylthio)iminocyclohexane (**11**): mp 146—147 °C (recrystallized from EtOH). *Anal.* Calcd for $C_{19}H_{19}N_3O_4S_2$: C, 54.66; H, 4.58; N, 10.06. Found: C, 54.51; H, 4.66; N, 9.88. IR ν_{max}^{KBr} cm^{-1}: 1527 (NO_2), 1507 (NO_2), 1336 (NO_2). ^{1}H-NMR ($CDCl_3$) δ:1.50 (3H, s, CH_3), 1.61 (1H, m, CH_2), 1.75 (1H, d, CH_2), 1.88 (1H, t, CH_2), 2.01—2.15 (2H, m, CH_2), 2.26 (1H, d, CH_2), 2.98—3.01 (2H, m, CH_2), 7.24—7.28 (3H, m, aromatic protons), 7.36 (1H, d, aromatic proton), 7.53 (1H, t, aromatic proton), 7.71 (1H, d, aromatic proton), 8.03 (1H, d, aromatic proton), 8.31 (1H, d, aromatic proton). MS *m/z*: 417 (M^+), 263 ($M^+ - O_2NC_6H_4S$), 154 ($O_2NC_6H_4S^+$).

5-Methyl-*N*,2-bis(*o*-nitrophenylthio)iminocyclohex-2-ene (**12**): mp 214.5—216 °C (recrystallized from ethyl acetate). *Anal.* Calcd for $C_{19}H_{17}N_3O_4S_2$: C, 54.92; H, 4.12; N, 10.11. Found: C, 54.75; H, 4.10; N, 10.10. IR ν_{max}^{KBr} cm^{-1}: 1510 (NO_2), 1338 (NO_2). ^{1}H-NMR ($CDCl_3$) δ: 1.20 (3H, d, CH_3), 2.20—2.37 (3H, m, CH_2 and CH), 2.62 (1H, d, CH_2), 3.10 (1H, d, CH_2), 7.13—7.24 (4H, m, aromatic proton), 7.36 (1H, t, aromatic proton), 7.37 (1H, d, aromatic proton), 7.62 (1H, d, aromatic proton), 8.14 (1H, d, aromatic proton), 8.20 (1H, d, aromatic proton). MS *m/z*: 416 (M^+), 215 ($M^+ - O_2NC_6H_4S$), 201 ($M^+ - O_2NC_6H_4SN$), 168 ($O_2NC_6H_4SN^+$), 154 ($O_2NC_6H_4S^+$).

4-Methyl-*N*,2-bis(*o*-nitrophenylthio)iminocyclohex-2-ene (**13**): mp 154—156 °C (recrystallized from ethyl acetate). *Anal.* Calcd for $C_{19}H_{17}N_3O_4S_2$: C, 54.92; H, 4.12; N, 10.11. Found: C, 54.75; H, 4.09; N, 9.96. IR ν_{max}^{KBr} cm^{-1}: 1510 (NO_2), 1338 (NO_2). ^{1}H-NMR ($CDCl_3$) δ: 1.26 (3H, d, CH_3), 1.74 (1H, m, CH_2), 2.19 (1H, d, CH_2), 2.64 (1H, t, CH_2),

2.75 (1H, m, CH), 3.05 (1H, d, CH_2), 7.08 (1H, d, vinyl proton), 7.14—7.21 (3H, m, aromatic protons), 7.37 (2H, q, aromatic protons), 7.62 (1H, d, aromatic proton), 8.14 (1H, d, aromatic proton), 8.19 (1H, d, aromatic proton). MS *m/z*: 416 ($M^+ + 1$), 215 ($M^+ - O_2NC_6H_4S$), 201 ($M^+ - O_2NC_6H_4SN$), 168 ($O_2NC_6H_4SN^+$), 154 ($O_2NC_6H_4S^+$).

N,2,2-Tris(*o*-nitrophenylthio)iminocycloheptane (**14**): mp 209—210 °C (dec., recrystallized from ethyl acetate). *Anal.* Calcd for $C_{25}H_{22}N_4O_6S_3$: C, 52.61; H, 3.88; N, 9.81. Found: C, 52.46; H, 3.69; N, 9.71. IR ν_{max}^{KBr} cm^{-1}: 1530 (NO_2), 1510 (NO_2), 1310 (NO_2). ^{1}H-NMR ($CDCl_3$) δ: 1.23 (1H, q, CH_2), 1.40 (1H, t, CH_2), 1.52 (1H, t, CH_2), 1.95 (2H, m, CH_2), 2.13 (1H, m, CH_2), 2.49 (1H, q, CH_2), 2.64 (2H, m, CH_2), 2.80 (1H, m, CH_2), 7.32—7.39 (3H, m, aromatic protons), 7.45 (2H, t, aromatic protons), 7.71 (1H, t, aromatic proton), 7.77 (2H, d, aromatic protons), 8.21 (2H, d, aromatic protons), 8.28 (1H, d, aromatic proton), 8.30 (1H, d, aromatic proton). MS *m/z*: 262 ($M^+ - 2(O_2NC_6H_4S)$), 154 ($O_2NC_6H_4S^+$).

Determination of 8 The electrolyzed solution obtained above (5 ml) was added to 1 ml of acetonitrile solution containing 2,4-dinitrophenylhydrazine (25 mM) and one drop of concentrated HCl, and refluxed for 30 min and then diluted to 10 ml with acetonitrile. Twenty microliters of the solution was injected into a NOVA-PAK cartridge column. The mobile phase was MeOH–CH_3CN–H_2O (60 : 5 : 35), and the detector was operated at 254 nm.

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