ELECTROCHEMISTRY OF 7-CARBOETHOXYCYCLOHEPTATRIENE AND ITS AZA-ANALOGUES: RING CONTRUCTION OF AZEPINE DERIVATIVES TO ANILINE DERIVATIVES BY OXIDATION AND N—N BOND RUPTURE OF DIAZEPINE DERIVATIVES TO 1-AMINO-4-CYANO-1,3-BUTADIENE DERIVATIVES BY REDUCTION

Satoru Kondo, Hiroshi Suzuki, Tatsuya Hattori, Takayasu Ido, and Katsuhiro Saito*

Department of Applied Chemistry, Nagoya Institute of Technology, Gokiso-cho, Showa-ku, Nagoya 466, Japan

Abstract—Electrochemical reduction or oxidation of 7-ethoxycarbonylcycloheptatriene afforded 2-ethoxycarbonylcycloheptatriene and ethyl phenylacetate, respectively. N-Alkoxycarbonyl-1H-azepine formed N-alkoxycarbonylaniline in electrochemical oxidation via a ring contraction. N-Alkoxycarbonyl-1H-1,2-diazepine afforded N-Alkoxycarbonyl-1-amino-4-cyano-1,3-butadiene in electrochemical reduction via an N-N bond fission.

Electrochemistry is useful not only for syntheses but also for investigations of reactivities of organic compounds. One of the merit of the electrochemical reaction is a possibility of an optional setting either in oxidation or reduction of the voltages of the electric potentials.1 Cyclohepta-1,3,5-triene derivatives are known to isomerize to bicyclo[4.1.0]hepta-2,4-diene derivatives or to form stable 6π-electrons aromatic systems, tropylium ion derivatives.2 1H-Azepine and 1H-1,2-diazepine derivatives are considered to be cyclic polyolefins with partial enamine-type reactivities rather than 8π-electrons anti-aromatic compounds. Their reactivities in thermal and photochemical reaction conditions3 or their reactions with organometallic compounds have been researched extensively.4 However, to our knowledge, it is hard to find any example in which azepine or diazepine derivatives have been a target for electrochemical reactions. As a series of our research on the reactivities of azepine and diazepine derivatives, we investigated the electrochemical reactions of 1H-azepine and 1H-1,2-diazepine derivatives. Here the results are reported. (Scheme 1)
A solution of 7-ethoxycarbonylcyclohepta-1,3,5-triene (1) in anhydrous acetonitrile was electrochemically reduced in the presence of tetrabutylammonium perchlorate (TBAP) as a supporting electrolyte with a platinum gauze as an anode and a platinum wire as a cathode at -1.4 V vs. Ag/Ag' at 0°C under a nitrogen stream. After evaporation of the solvent the reaction mixture was column followed by thin layer chromatographed on silica gel to give 2-ethoxycarbonylcyclohepta-1,3,5-triene (4) in 36% yield. The current efficiency was 60%. On the other hand, 1 resisted to electrochemical oxidation and finally gave a low yield (5%) of ethyl phenylacetate (5) at +2.0 V vs. Ag/Ag' through a current efficiency of 3%.

Electrochemical reduction of N-ethoxycarbonyl- (2a) and N-methoxycarbonyl-1Hazarine (2b) at the analogous reaction conditions as above but under variable voltages resulted in a formation of an intractable complicated mixture. However, electrochemical oxidation of 2a and 2b at +2.0 V vs. Ag/Ag' afforded fairly good yields of N-ethoxycarbonyl- (6a) and N-methoxycarbonylaniline derivative (6b) in 62% and 79% yields, respectively. The current efficiencies were 25% and 40%, respectively.

Scheme 1
$N^\text{-Ethoxycarbonyl-}$ (3a) and $N^\text{-methoxycarbonyl-1H-1,2-diazepine}$ (3b) were electrochemically reduced at $-1.4 \text{ V vs. Ag/Ag}^+$ to give $N^\text{-ethoxycarbonyl-}$ (7a) and $N^\text{-methoxycarbonyl-1-amino-4-cyano-1,3-butadiene}$ (7b)\(^4\) in 56% (current efficiency 44%) and 58% (54%) yields, respectively.

The reaction mechanism of the electrochemical reduction of 1 is considered to be analogous to that of 1,3-hydrogen migration of 7-cyanocyclohepta-1,3,5-triene under basic conditions reported by Takahashi and her coworkers.\(^5\) (Scheme 2)

One electron reduction of 1 generates a radical anion (8), in which the hydrogen at the 7-position migrates to the 2-position. The preferential occurrence of the 1,3-migration is attributable to the co-planarity of the three carbon atoms at 1, 2, and 7-positions, which are concerning in the present hydrogen migration.\(^6\)

The formation of ethyl phenylacetate (5) can be explained as follows. One electron release from the carbonyl group of 1 forms a ketyl-type cation radical (9). It is well known that the isomerization between a cycloheptatriene system (9) and a bicyclo[4.1.0]heptadiene system (10) favors to the later when the substituent is electron-withdrawing.\(^7\) Thus, 1 becomes to be easy to isomerize to the bicyclic system (10) by electrochemical oxidation. An aromatization of 10 employing a proton elimination followed by an extraction of proton radical from solvent can form 5.

![Scheme 2](image-url)
The reaction mechanism of azepine derivatives (2) is considered to be as analogous to that of the formation of 5. (Scheme 2) One electron oxidation of 2 generates a cation radical (11), which tautomerizes to 12, and finally aromatizes to the aniline derivative (6). Reported transformation of 2 to 6 in acidic media well support this mechanism. An electrochemical reduction of 3 can be explained to proceed as follows. One electron transfer to 3 forms an anion radical (13), which ruptures the N-N bond to form an imino radical-type anion radical (14), which then generates the cyano compound (7) through a proton radical elimination followed by a proton extraction from solvent. This mechanism is essentially same as those of a formation of 7 from 3 by reactions with bases or with appropriate metals.

The failure of 2 and 3 in electrochemical reduction to form the hydrogen migrating products of the type 4 is apparently attributable to the lack of the corresponding hydrogen (7-position hydrogen in 1) in 2 and 3, which should migrate.

ACKNOWLEDGEMENT
The authors are indebted to Dr. Kazuaki Ito of Yamagata University for his fruitful suggestions.

EXPERIMENTAL

The working electrode was a combination of a platinum gauze of a size 5 cm depth and 12 cm width and a platinum wire, which were separated each other by means of a medium-porosity sintered glass frit. The reference electrode was a silver wire. The controlled potential power was supplied from a Yanaco Potentio/Galvanostatic Electrolyser VE-9 apparatus. Acetonitrile was distillated from calcium hydride and used immediately. Wakogel C-200 and Wakogel B5-F were used for column and thin layer chromatographies, respectively.

Typical reactions are mentioned below.

**Electrochemical Reduction of 7-Ethoxycarbonyl-1,3,5-cycloheptatriene (1).** A solution of 1 (151 mg, 0.92 mmol) and TBAP (1.57 g, 4.60 mmol) in anhydrous acetonitrile (100 mL) was electrolyzed at -1.4 V vs. Ag/Ag⁺ at 0°C under a nitrogen stream for 20 min. 52.8 Coulomb of electricity was passed. After evaporation of the solvent, the reaction mixture was column chromatographed on silica gel with an eluent of hexane-ethyl acetate (19:1) to give a colorless oil, which was further purified by thin layer chromatography on silica gel with a developing solvent of hexane-ethyl acetate (19:1) to give 4 (54 mg, 35.8 %, R₇=0.60, current efficiency 82.2 %).

**Electrochemical Oxidation of 7-Ethoxycarbonyl-1,3,5-cycloheptatriene (1).** A solution of
1 (512 mg, 3.12 mmol) and TBAP (6.93 g, 0.20 mmol) in anhydrous acetonitrile (200 mL) was electrolyzed at +2.0 V vs. Ag/Ag⁺ at 0°C under a nitrogen stream. 194 Coulomb of electricity was passed. After evaporation of the solvent, the reaction mixture was column chromatographed on silica gel with an eluent of hexane-ethyl acetate (19:1) to give a colorless oil, which was further purified by thin layer chromatography on silica gel with a developing solvent of hexane-ethyl acetate (19:1) to give 5 (14.9 mg, 2.9 %, Rᶠ=0.55, current efficiency 15.5 %).

Electrochemical Oxidation of N-Ethoxycarbonyl-1H-azepine (2a). A solution of 2a (471 mg, 3.12 mmol) and TBAP (6.93 g, 20.3 mmol) in anhydrous acetonitrile (200 mL) was electrolyzed at +2.0 V vs. Ag/Ag⁺ at 0°C under a nitrogen stream. 546 Coulomb of electricity was passed. After evaporation of the solvent, the reaction mixture was column chromatographed on silica gel with an eluent of hexane-ethyl acetate (4:1) to give a yellow oil, which was further purified by thin layer chromatography on silica gel with a developing solvent of hexane-ethyl acetate (3:1) to give 6 (336 mg, 71.3 %, Rᶠ=0.50, current efficiency 39.2 %).

Electrochemical Reduction of N-Ethoxycarbonyl-1H-1,2-diazepine (3a). A solution of 3a (140 mg, 0.92 mmol) and TBAP (1.59 g, 4.65 mmol) in anhydrous acetonitrile (100 mL) was electrolyzed at -1.4 V vs. Ag/Ag⁺ at 0°C under a nitrogen stream. 68.9 Coulomb of electricity was passed. After evaporation of the solvent, the reaction mixture was column chromatographed on silica gel with an eluent of hexane-ethyl acetate (3:2) to give colorless crystals, which were further purified by thin layer chromatography on silica gel with a developing solvent of hexane-ethyl acetate (3:7) to give 7 (59 mg, 42.2 %, Rᶠ=0.50, current efficiency 54.3 %).

REFERENCES AND FOOTNOTES
A formation of the complicated mixture in electrochemical reduction of 2 may be explained by the instability of the vinyl radical-type anion radical (15), which is expected to be formed by reduction of 2. A decomposition or a polymerization of 15 can form the complicated mixture.

Scheme 3

One electron oxidation of 3 can form two kinds of cations. An electron removal from the carbonyl group generates a cation (16) and a removal from the system of the ring part form a conjugated cation (18). If the same type of a valence isomerization as those of 9 takes a place in 16, a diaziridine-type cation (17) may be generated. An instability of 17 due to the aziridine-structure can be a reason of the formation of the complicated mixture by decomposition.

An N-N bond fission in 18 generates 19. Removal of proton to form a cyano group and a catch of hydrogen from an appropriate source can form 7.

A failure to form 7 in the electrochemical oxidation of 3 may show that 18 should not be formed or it is too unstable to form 19 via the N-N bond rupture course.