HETEROCYCLES, Vol. 48, No. 6, 1998

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

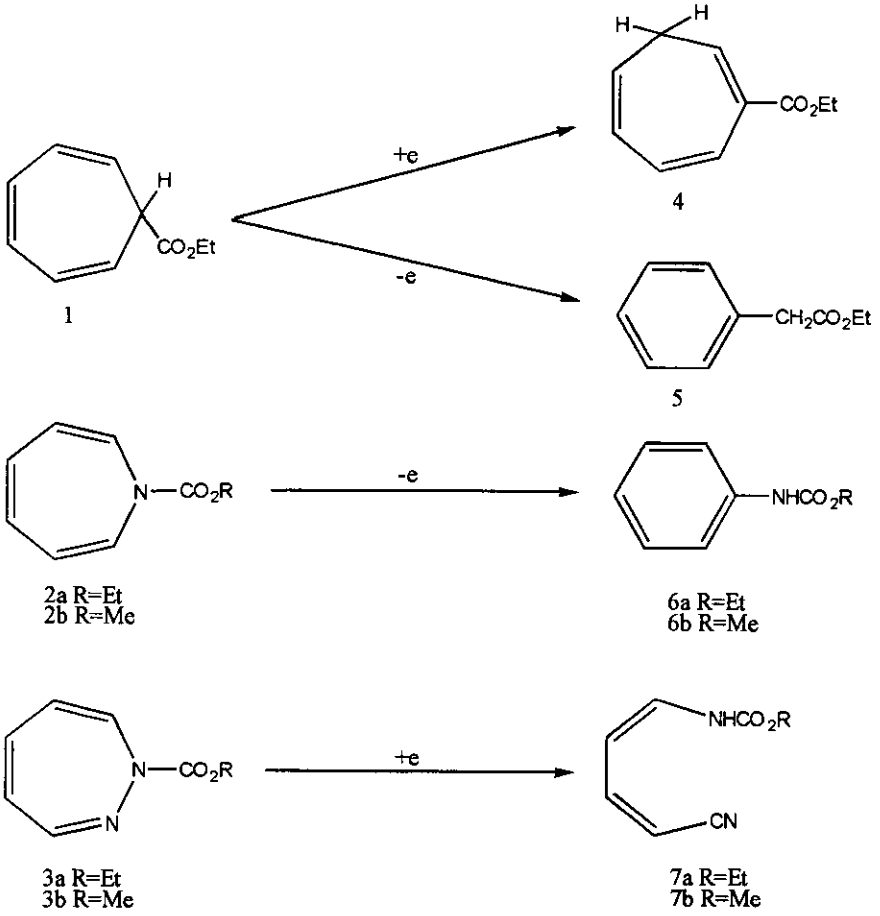
Abstract—Electrochemical reduction or oxidation of 7-ethoxycarbonylcycloheptatriene afforded 2-ethoxycarbonylcycloheptatriene and ethyl phenylacetate, respectively. *N*-Alkoxycarbonyl-1*H*-azepine formed *N*-alkoxycarbonylaniline in electrochemical oxidation *via* a ring contruction. *N*-Alkoxycarbonyl-1*H*-1,2-diazepine 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] 1*H*-Azepine and 1*H*-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 conditions[3] 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 1*H*-azepine and 1*H*-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 perchrolate (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℃ 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)[5] 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-1*H*-azepine (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.[6] The current efficiencies were 25 % and 40 %, respectively.

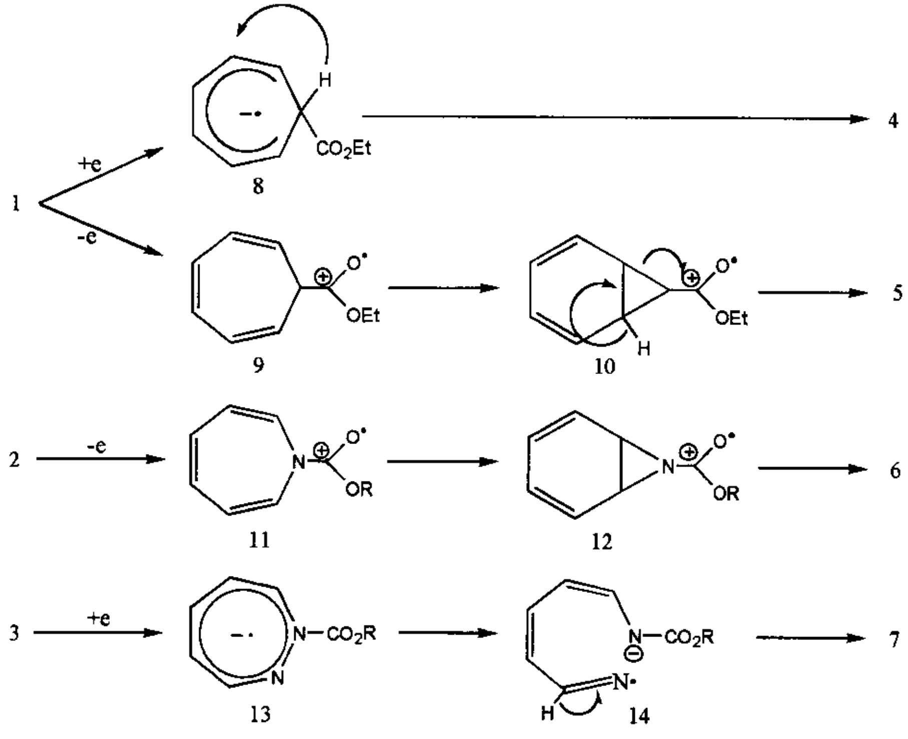


Scheme 1

N-Ethoxycarbonyl- (3a) and *N*-methoxycarbonyl-1*H*-1,2-diazepine (3b) were electrochemically reduced at −1.4 V vs. Ag/Ag^+ to give *N*-ethoxycarbonyl- (7a) and *N*-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-planality of the three carbon atoms at 1, 2, and 7-positions, which are concerning in the present hydrogen migration.[5]

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

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.[8]
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.[9]
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.[10]

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℃ 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 %, R_f=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℃ 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 %, R_f=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℃ 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 %, R_f=0.50, current efficiency 39.2 %).

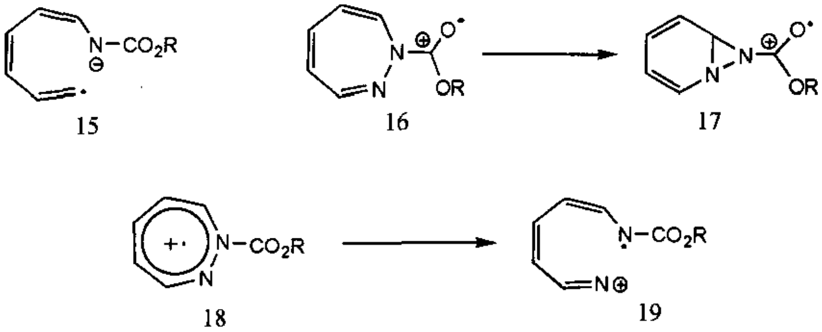
Electrochemical Reduction of N-Ethoxycarbonyl-1H-1,2-diazepine (3a). A solution of 3a (140 mg, 0.92 mmol) and TBAP (1.59 g, 4.65 mmol) in anhydrous acetonitrile (100 mL) was electrolyzed at −1.4 V vs. Ag/Ag$^+$ at 0℃ under a nitrogen stream. 68.9 Coulomb of electricity was passed. After evaporation of 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 %, R_f=0.50, current efficiency 54.3 %).

REFERENCES AND FOOTNOTES

1. D. Seebach, *Angew. Chem., Int. Ed. Engl.*, 1979, 18, 239; P. G. Gassmann, O. M. Rasmy, T. O. Murdock, and K. Saito, *J. Org. Chem.*, 1981, 46, 5455.
2. W. Tochtermann, C. Degel, H. O. Horstmann, and D. Krauss, *Tetrahedron Lett.*, 1970, 4719; W. D. Stohrer, *Chem. Ber.*, 1973, 106, 970.
3. R. A. Acheson, “An Introduction to the Chemistry of Heterocyclic Compounds”, John Willey and Sons, Inc., 1976; J. Streith, J. P. Luttringer, and M. Nastasi, *J. Org. Chem.*, 1971, 36, 2962; S. Ito, Y. Yokoyama, T. Okumoto, K. Saito, K. Takahashi, K. Satake, H. Takamuku, M. Kimura, and S. Morosawa, *Bull. Chem. Soc. Jpn.*, 1990, 63, 3162; K. Saito, A. Yoshino, H. Watanabe, and K. Takahashi, *Heterocycles,* 1992, 34, 497.
4. K. Saito, S. Iida, and T. Mukai, *Bull. Chem. Soc. Jpn.*, 1984, 57, 3483; K. Saito, T. Mukai, and S. Iida, *ibid.*, 1986, 59, 2485; K. Saito, Y. Horie, and K. Takahashi, *J. Organometal.*

Chem., 1989, 363, 231; K. Saito, M. Kozaki, and K. Takahashi, *Heterocycles,* 1990, 31, 1491; K. Saito, A. Yoshino, and K. Takahashi, *ibid.*, 1991, 32, 1.

5. K. Takahashi, H. Yamamoto, and T. Nozoe, *Bull. Chem. Soc. Jpn.*, 1970, 43, 200.
6. L. A. Paquette, D. E. Kuhla, and J. H. Barrette, *J. Org. Chem.*, 1969, 34, 2879; J. Streith, J. P. Luttringer, and M. Nastasi, *ibid.*, 1971, 36, 2962; K. Saito, H. Kojima, T. Okudaira, and K. Takahashi, *Bull. Chem. Soc. Jpn.*, 1983, 56, 175; M. Nitta and H. Miyama, *Heterocycles,* 1986, 24, 1411.
7. R. Hoffmann, *Tetrahedron Lett.*, 1970, 2907; H. Gunther, *ibid.*, 1970, 5173.
8. H. Prinzbach and H. Babsh, *Tetrahedron Lett.*, 1997, 1355; L. A. Paquette, D. E. Kuhla, and J. H. Barrette, *J. Org. Chem.*, 1969, 34, 2879.
9. K. Saito, H. Kojima, T. Okudaira, and K. Takahashi, *Bull. Chem. Soc. Jpn.*, 1983, 56, 175; K. Saito, Y. Horie, and K. Takahashi, *J. Organometal. Chem.*, 1989, 363, 231; K. Saito, M. Kozaki, and K. Takahashi, *Heterocycles,* 1990, 31, 1491.
10. 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.

Received, 5th January, 1998