

ONE-STEP SYNTHESIS AND ELECTROCHEMICALLY ENHANCED
CATION-BINDING PROPERTIES OF NOVEL "QUINONOID CROWN ETHERS"

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Novel crown ethers bearing reducible quinonoid functions were readily prepared by applying oxidative C-C coupling to the ring-closure step of acyclic polyether precursors. They showed highly enhanced cation-binding properties for Li⁺ cation upon electrochemical reduction, which were not observed with simple quinone.

Macrocyclic crown ethers bearing electroactive groups have recently attracted considerable attentions. When quinone,¹⁾ nitrobenzene,²⁾ and other redox centers³⁾ were attached to the ion-binding crown ether systems, their electrochemical and related reactions were coupled with cation-complexations of crown ether moieties. Here we report an one-step synthesis of novel crown ethers bearing reducible quinonoid functions, "quinonoid crown ethers", of which electrochemically reduced forms bind Li⁺ cation about 10⁴ times more strongly than the original forms. Since naturally occurring and synthetic quinonoid compounds play important roles in photochemistry, biochemistry, physiology, and electrochemistry,⁴⁾ the present new "quinonoid crown ethers" may offer the further possibilities in coupling various quinonoid functions with host-guest complexations of crown ether compounds.

As a new synthetic approach to quinonoid crown ethers, we applied oxidative C-C coupling reaction to the ring-closure step of acyclic precursors (Figure 1). Although high dilution techniques, template reactions, and other synthetic strategies have been developed,⁵⁾ we successfully performed an one-step synthesis of novel crown ethers without any complicated procedures. Typically, to a stirred MeCN solution of tetraethylene glycol precursor 1a (1 mmol/40 ml), an aqueous solution of ammonium cerium(IV) nitrate (2 mmol/40 ml) was

dropped at room temperature. After 30 min., the reaction mixture was extracted with CHCl_3 . The extract was dried over MgSO_4 , evaporated, and chromatographed on silica gel (EtOAc). Pure $\underline{2a}$ was obtained by crystallization from hexane/ CCl_4 . Compound $\underline{3a}$ was also prepared by oxidation of $\underline{1a}$ or $\underline{2a}$. $^1\text{H-Nmr}$ spectra of $\underline{2a}$ and $\underline{3a}$ supported that C-C coupling occurred at 4'-positioned carbons of phenyl rings of the precursor $\underline{1a}$. Other members $\underline{2b}$, $\underline{2c}$, $\underline{3b}$, and $\underline{3c}$ were similarly prepared via cerium oxidation in comparable yields.⁶⁾ Although high dilution conditions and template-type reactions were attempted, the yields indicated in Figure 1 were not improved.

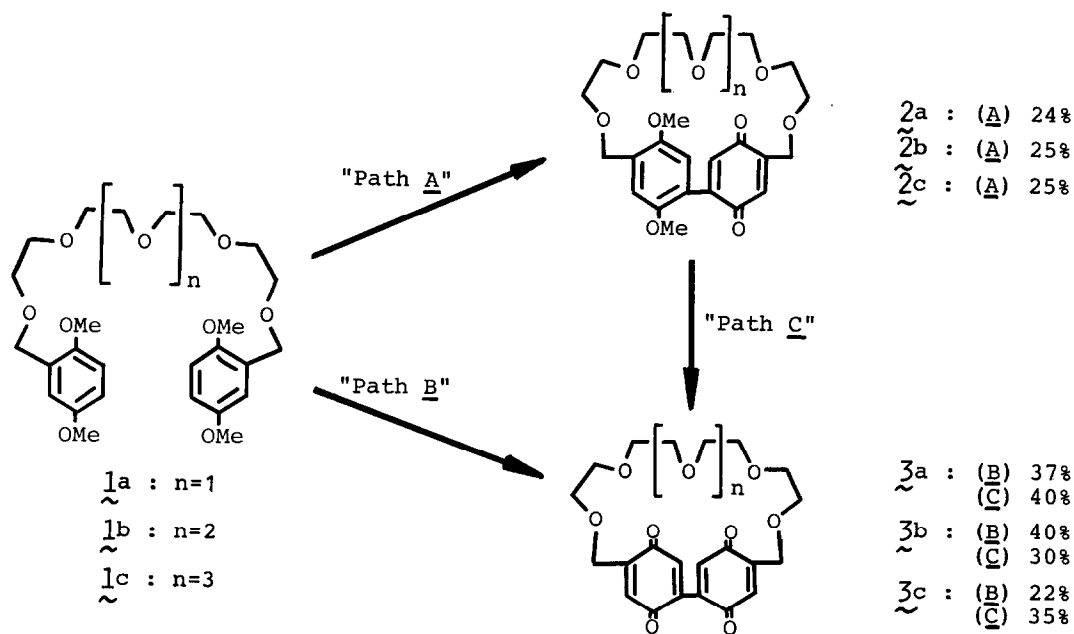
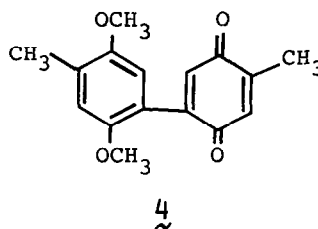
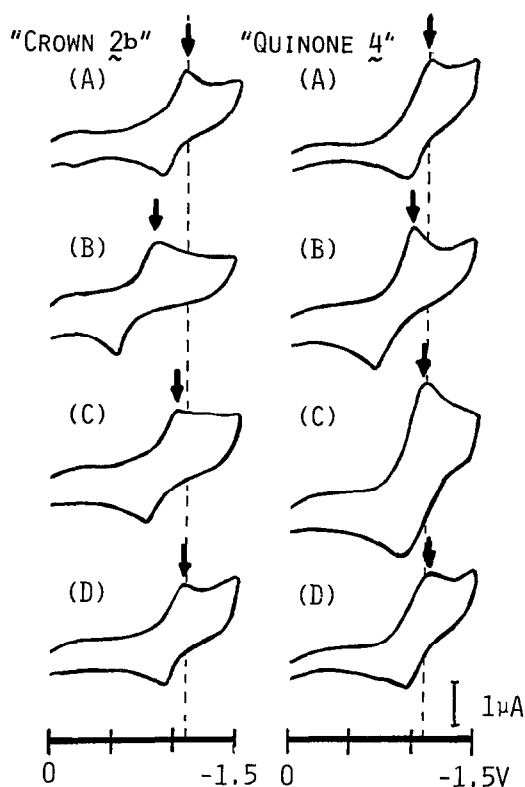


Figure 1. Synthesis of Novel "Quinonoid Crown Ethers" via Oxidative C-C Coupling Cyclization.

$\text{Ce(IV)}/\underline{1}$: 2 eq. (path A), 6 eq. (path B). $\text{Ce(IV)}/\underline{2}$: 6 eq. (path C).

The absorption spectra of quinonoid crown ethers $\underline{2a-c}$ and $\underline{3a-c}$ in MeCN were slightly changed by addition of a large excess of metal perchlorates. Although KClO_4 and NaClO_4 provided larger spectral changes than LiClO_4 , their deviations were too small to be quantitatively analyzed. In the other words, these quinonoid crown ethers seemed to form somewhat unstable complexes with alkali metal ions.



Electrochemical measurements were conducted under N_2 in dried CH_3CN 0.1M in Et_4NClO_4 . A standard H-cell, glassy carbon, and Pt-wire electrodes were used. Peak potential was recorded vs $Ag/0.1M-AgClO_4$ in CH_3CN . Scan rate, 100mV/sec. Reproducibility, $\pm 10mV$.

Figure 2. Cyclic Voltammograms for Quinonoid Crown ether 2b and Quinone 4 in the (A) absence and presence of (B) $LiClO_4$, (B) $NaClO_4$, and (D) $KClO_4$ Salts. Arrows indicate the first reduction peaks. Other conditions: see Ref. 7).

Electrochemical reactions of quinonoid crown ethers 2a-c were studied by cyclic voltammetric techniques. Since electrochemically reduced quinone group, semiquinone, can be more effective ligating donor than its neutral form, cation-binding abilities of the quinonoid crown ethers were expected to be enhanced by electrochemical reduction. As shown in Figure 2, addition of $LiClO_4$ to the MeCN solution of crown ether 2b offered large anodic shift (260 mV) in the reduction peak potentials, while $NaClO_4$ and $KClO_4$ induced much smaller shifts of 80 mV and 30 mV.⁷⁾ These shifts clearly indicate that electrochemically reduced crown ether 2b binds Li^+ cation much more strongly than its oxidized form. According to the reported calculation method,⁸⁾ its electrochemical enhancements of cation-binding abilities were factors of 25000 for Li^+ , 22 for Na^+ , and 3 for K^+ ions.

The quinonoid compound 4 also showed similar cation-dependent redox reactions, but its cation-binding increases were only 105-fold for Li^+ , 2.2-fold for Na^+ , and 0.5-fold for K^+ cations. These observations strongly suggest that simple ion-pairing between metal cation and semiquinone could not cause large shifts in reduction potentials and enhanced cation-binding abilities as observed in quinonoid crown ether 2a-c systems.⁹⁾ Probably, the proximity of electroactive quinone group to the ion-binding crown ether unit brought about coupling redox reaction with cation-complexation. Further applications of redox-responsive crown ethers of this type in transport and related processes are ongoing.

References and Notes

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- 6) 2a: red crystal (mp 116°C); Mass(m/z) 462(M^+); $^1\text{H-NMR}$ (CDCl_3 , 400MHz, δ) 2.94-3.70(m, 16H), 3.79(s, 3H), 3.83(s, 3H), 4.42(b, 2H), 4.62(s, 2H), 6.84(s, 1H), 6.89(s, 1H), 6.96(s, 1H), 7.10(s, 1H); IR(KBr) 1660 cm^{-1} ; Found C 62.03, H 6.65%. Calcd C 62.03, H 6.54%. 3a: yellow crystal (mp 126-127°C); Mass(m/z) 432(M^+); $^1\text{H-NMR}$ (CDCl_3 , 400MHz, δ) 3.31, 3.40, 3.68 (m, 16H), 4.41(bs, 4H), 6.93(t, 2H), 6.99(s, 2H); IR(KBr) 1660 cm^{-1} ; Found C 60.79, H 5.83%. Calcd C 60.82, H 5.59%.
Other obtained crown ethers were also isolated as crystals and showed satisfactory spectral and elemental analysis data.
- 7) 30 equivalent of metal perchlorates were added to 0.3 mM solutions of quinonoid compounds, excepting for KClO_4 (7 eq.). When 7 equivalent of LiClO_4 was added, the reduction potential of crown ether 2b shifted anodically by 220 mV.
- 8) Electrochemical enhancement of stability constants(K_b/K_a) is calculated from $E^2 - E^1 = - (RT/nF) \ln(K_a/K_b)$. E: Reduction potential of quinone in the (1) absence or (2) presence of metal salt; K: Stability constant for (a) oxidized or (b) reduced quinone compound. Also see Ref. 2).
- 9) Electrochemically enhanced Li^+ -binding for 2a and 2c were estimated as 7800 times and 17000 times, respectively.

(Received in Japan 28 March 1985)