PREPARATION OF AZULENEQUINONES CONTAINING AZACROWN
MOIETIES AND THE SINGULAR COMPLEXATION OF SODIUM OR
POTASSIUM CATION BY 3,5-BIS(AZA-18-CROWN-6)-1,7-AZULENE-
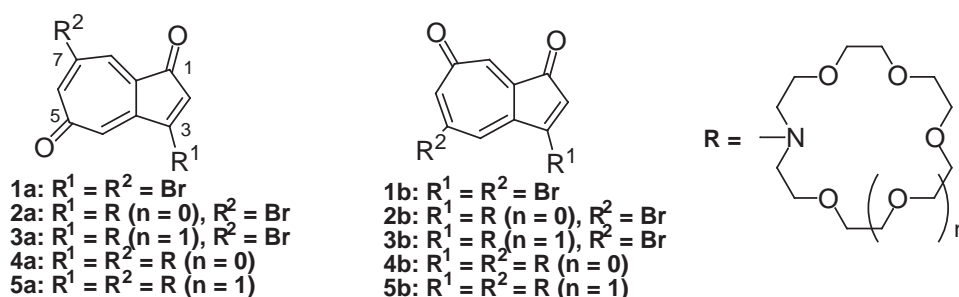QUINONE IN SOLUTION

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Abstract - Efficient syntheses of azulenequinones containing azacrown ether
moieties as pendants (**2**) (**5**) were carried out. The singular complexation
properties of 3,5-bis(aza-18-crown-6)-1,7-azulenequinone (**5b**) with sodium
or potassium cation were investigated by ^{1}H NMR measurement.

Macrocyclic receptors having cation selective chromophore or redox properties are interesting class of
compounds. To this direction, we designed azulenequinones (AzQs) containing azacrown ether moieties.
AzQs are novel and one of the most interesting classes of nonbenzenoiod quinones and their chemical and
physical properties are of particular interest in connection with benzenoid quinones.[1-5] We reported the
nucleophilic substitution of 3,7-dibromo-1,5-AzQ (**1a**) and 3,5-dibromo-1,7-AzQ (**1b**) and their value as
synthons for various kinds of disubstituted-AzQs; the five-membered ring moiety is more reactive than the
seven-membered ring one.[6]

We report herein the syntheses and physical properties of azacrown AzQs (**2a,b**) (**5a,b**) from
dibromo-AzQs (**1a,b**), and the complexation properties of 3,5-bis(aza-18-crown-6)-1,7-azulenequinone
(**5b**) with sodium or potassium cation in solution.

1a: R^1 = R^2 = Br
2a: R^1 = R (n = 0), R^2 = Br
3a: R^1 = R (n = 1), R^2 = Br
4a: R^1 = R^2 = R (n = 0)
5a: R^1 = R^2 = R (n = 1)

1b: R^1 = R^2 = Br
2b: R^1 = R (n = 0), R^2 = Br
3b: R^1 = R (n = 1), R^2 = Br
4b: R^1 = R^2 = R (n = 0)
5b: R^1 = R^2 = R (n = 1)

Monoazacrown-1,5-AzQs (**2a**) and (**3a**) and -1,7-AzQs (**2b**) and (**3b**), which are pale yellow or yellow
needles, were synthesized in good to moderate yields by the reaction of dibromo-AzQs (**1a**) and (**1b**) with
3 mol *equiv.* of 1-aza-15-crown-5 (1A15C5) and 1-aza-18-crown-6 (1A18C6) respectively in THF at room
temperature for 2 23 h (Table 1).

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Dedicated to Professor Shô Itô on the occasion of his 77th birthday.

On the other hand, when **1a** or **1b** was treated with excess amount (20 mol *equiv.*) of 1A15C5 or 1A18C6 in ethanol under reflux conditions for 17 ～ 44 h, 3,7-disubstituted 1,5-AzQs (**4a**) and (**5a**) or 3,5-disubstituted 1,7-AzQs (**4b**) and (**5b**) were obtained respectively as yellow to orange solids (Table 1).

Table 1. Yields, appearance, and melting points of AzQs containing azacrown ethers

Compound	Yield (%)[a]	Appearance	mp (°C)
2a	74	yellow needles	176-177
2b	73	yellow needles	125-126
3a	70	pale orange needles	111-112
3b	74	yellow needles	108-109
4a	73	pale yellow solids	135.5-137
4b	55	orange crystals	164-165
5a	57	orange solids	96-97
5b	33	yellow solids	58-61

a) Isolated yield

The ^{1}H NMR, IR and MS spectral and analytical data of those compounds are given in Table 2. Those data are coincided with the structures proposed for **2a**,**b**, **3a**,**b**, **4a**,**b** and **5a**,**b** respectively.

Table 2. Elemental analysis and IR, ^{1}H NMR, and MS spectral data for AzQs containing azacrown ethers

Compound (Formula)	Found (%) (calcd) C	H	N	ν_{max}[a]/cm^{-1}	δ_H (CDCl$_3$, 400 MHz)	m/z (EI)
2a ($C_{20}H_{24}BrNO_6$)	53.00 (52.87)	5.33 (5.32)	2.92 (3.08)	2890, 1679, 1592, 1549, 1124	3.63 (4H, s), 3.65-3.71 (8H, m), 3.76 (4H, t, J 5.9), 3.86 (4H, t, J 5.9), 5.69 (1H, s), 7.24 (1H, d, J 2.2), 7.32 (1H, t, J 2.2), 7.41 (1H, d, J 2.2)	455 (100%, M$^+$+2), 453 (97.7, M$^+$), 374 (21.6), 346 (25.2)
2b ($C_{20}H_{24}BrNO_6$)	53.00 (52.87)	5.30 (5.32)	2.97 (3.08)	2880, 1678, 1598, 1556, 1128	3.66 (4H, s), 3.68-3.75 (8H, m), 3.75 (4H, t, J 5.8), 3.89 (4H, t, J 5.7), 5.66 (1H, s), 7.17 (1H, d, J 2.7), 7.36 (1H, dd, J 2.7, 1.5), 7.81 (1H, d, J 1.5)	455 (100%, M$^+$+2), 453 (98.2, M$^+$), 374 (60.4), 346 (24.3)
3a ($C_{22}H_{28}BrNO_7$)	53.36 (53.02)	5.82 (5.66)	2.58 (2.81)	2874, 1682, 1576, 1558, 1118	3.65 (8H, s), 3.65-3.70 (8H, m), 3.86 (8H, br s), 5.70 (1H, s), 7.23 (1H, br s), 7.32 (1H, t, J 2.1), 7.40 (1H, d, J 2.1)	499 (88.6%, M$^+$+2), 497 (89.5, M$^+$), 418 (14.6), 390 (12.9)
3b ($C_{22}H_{28}BrNO_7$)	53.02 (53.02)	5.75 (5.66)	2.68 (2.81)	2874, 1689, 1593, 1559, 1124	3.60-3.75 (16H, m), 3.82 (4H, br t, J 4.7), 3.88 (4H, t, J 5.0), 5.68 (1H, s), 7.16 (1H, d, J 2.4), 7.32 (1H, t, J 2.4), 7.76 (1H, br s)	499 (75.3%, M$^+$+2), 497 (73.6, M$^+$), 418 (69.3), 390 (13.3)
4a ($C_{30}H_{44}N_2O_{10}$)	60.67 (60.80)	7.51 (7.48)	4.58 (4.73)	2871, 1683, 1637, 1558, 1123	3.63 (4H, s), 3.64 (4H, s), 3.66 (8H, s), 3.68 (8H, s), 3.73 (4H, t, J 5.8), 3.79 (4H, t, J 5.3), 3.80 (4H, t, J 5.3), 3.87 (4H, t, J 5.8), 5.60 (1H, s), 6.11 (1H, dd, J 3.2, 1.6), 7.03 (1H, d, J 1.6), 7.31 (1H, d, J 3.2)	592 (5.7%, M$^+$), 564 (6.1), 548 (3.9), 536 (7.4)
4b ($C_{30}H_{44}N_2O_{10}$)	60.78 (60.80)	7.53 (7.48)	4.58 (4.73)	2869, 1682, 1645, 1557, 1122	3.62 (4H, s), 3.64 (4H, s), 3.65 (8H, s), 3.64-3.70 (8H, m), 3.70 (4H, t, J 5.7), 3.77 (4H, t, J 5.9), 3.79 (4H, t, J 5.7), 3.87 (4H, t, J 5.9), 5.63 (1H, s), 6.10 (1H, dd, J 2.4, 2.3), 7.8 (1H, d, J 2.4), 7.31 (1H, d, J 2.3)	592 (7.4%, M$^+$), 564 (5.0), 548 (6.9), 536 (7.1)
5a ($C_{34}H_{52}N_2O_{12}$)	60.15 (59.99)	7.80 (7.70)	3.95 (4.12)	2871, 1682, 1640, 1559, 1114	3.66 (8H, s), 3.67 (24H, s), 3.75-3.81 (8H, m), 3.83-3.88 (8H, m), 5.59 (1H, s), 6.10 (1H, dd, J 3.1, 0.9), 7.04 (1H, br d, J 0.9), 7.35 (1H, d, J 3.1)	680 (24.0%, M$^+$), 652 (4.5), 418 (5.4)
5b ($C_{34}H_{52}N_2O_{12}$)	59.97 (59.99)	7.81 (7.70)	3.99 (4.12)	2872, 1682, 1645, 1558, 1114	3.61-3.69 (32H, m), 3.75 (8H, br s), 3.84 (8H, br s), 5.63 (1H, s), 6.13 (1H, t, J 2.4), 7.12 (1H, d, J 2.4), 7.31 (1H, d, J 2.4)	680 (16.1%, M$^+$), 652 (11.5), 418 (6.3)

a) Compounds **4** and **5** were measured in neat.

UV-VIS spectral and cyclic voltammogram (CV) data were shown in Table 3. Compared with dibromo-AzQs (**1**) (*ca.*390 nm), monoazacrown-AzQs (**2**) and (**3**) (405-412 nm) show bathochromic shifts for the longest-wave-maximum because of electrondonating resonance effect from nitrogen. For disubstituted-AzQs (**4**) and (**5**) the longest-wave maximum shows hypsochromic shifts (*ca.*350 nm), indicating a distorted geometry of AzQ skeleton; the PM3 calculation[7] of **1a** and **1b** suggests a non-planar

structures for their most stable forms. Addition of alkali metal ions such as lithium, sodium and potassium to the AzQs (**2**)～(**5**) does little change their UV-VIS spectra, suggesting that metal ions coordinate to crown parts of flexible *N*-pivots without complexation to nitrogen atoms.

The redox potentials ($E^1_{1/2}$) of AzQs are in the order of **1a** > **2a** > **3a** > **4a** > **5a** and **1b** > **2b** > **3b** > **4b**

　5b, where 1,7-AzQ series show slightly higher values than 1,5-AzQ series. CVs of AzQs (**2**)～(**5**) and metal coordinated ones showed poor reversibility.

Table 3. UV-VIS spectra and CV data for AzQs containing azacrown ethers

Compound	λ_{max}/nm (log ε), CH₃CN	$E_{1/2}$ (V vs. SCE), CH₃CN
1a	395.0 (3.62), 375.0 (3.92), 271.0 (4.41), 221.5 (4.49)	-0.58 [a),b)]
1b	392.0 (3.80), 372.0 (3.80), 263.0 (4.61), 242.0 (4.62)	-0.62 [a)b)]
2a	412.0 (3.63), 328.5 (3.99), 258.5 (4.43)	-1.00 [b)], -1.22 [b)]
2b	405.0 (3.70), 332.5 (4.23), 258.0 (4.58)	-0.97 [b)], -1.23 [b)]
3a	411.0 (3.81), 329.5 (4.15), 259.0 (4.54)	-1.06 [a),b)]
3b	407.5 (3.59), 332.5 (4.12), 258.0 (4.48)	-1.02 [a),b)]
4a	351.0 (4.24), 314.0 (4.42), 258.5 (4.54)	-1.24 [b)], -1.50 [b)]
4b	349.5 (4.29), 314.0 (4.47), 259.0 (4.57)	-1.21 [b)], -1.47 [b)]
5a	351.0 (4.17), 314.0 (4.36), 259.0 (4.49)	-1.32 [c)], -1.59 [c)]
5b	349.0 (4.06), 313.0 (4.24), 259.5 (4.34)	-1.20 [c)], -1.48 [c)]

a) Two electron redox wave. b) Irreversible wave. c) Quasi-reversible wave.

Thus, to our disappointment, neither the expected functionality as a color sensor nor a metal ion transfer carrier using their redox property[8] was recognizable. However, singular behaviors of **5b** for alkali metal ions, sodium and potassium, were observed during the survey of the ability of those compounds as a host for cation coordination. ¹H NMR spectral changes of **5b** in acetonitrile-d₃ were recorded in accordance with the addition of sodium or potassium cations (Figure 1).
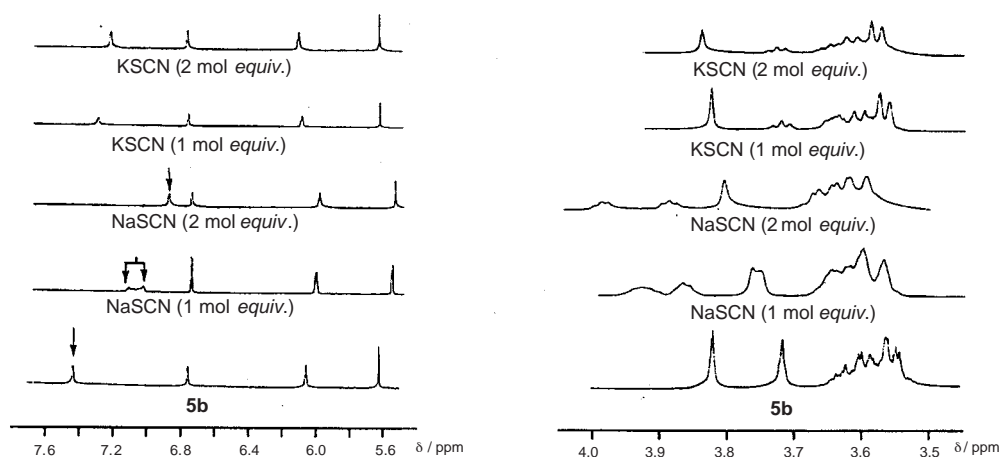

Figure 1 ¹H NMR of **5b** in the presence of NaSCN or KSCN.

When 1 mol *equiv.* of sodium thiocyanate was added, the signals at δ 7.42 (H-4) and δ 5.62 (H-2) shifted upfield and both splitted into two signals at δ 7.11 and δ 7.04 and δ 5.57 and δ 5.56 respectively, indicating the existence of two isomers clearly. When 2 mol *equiv.* of sodium thiocyanate were added, the spectral pattern was simple, indicating the existence of a single isomer. These phenomena were peculiar in **5b** and not observed in **2**, **3**, **4** and **5a**. The unusual behaviors could be explained as follows (Schemes 1
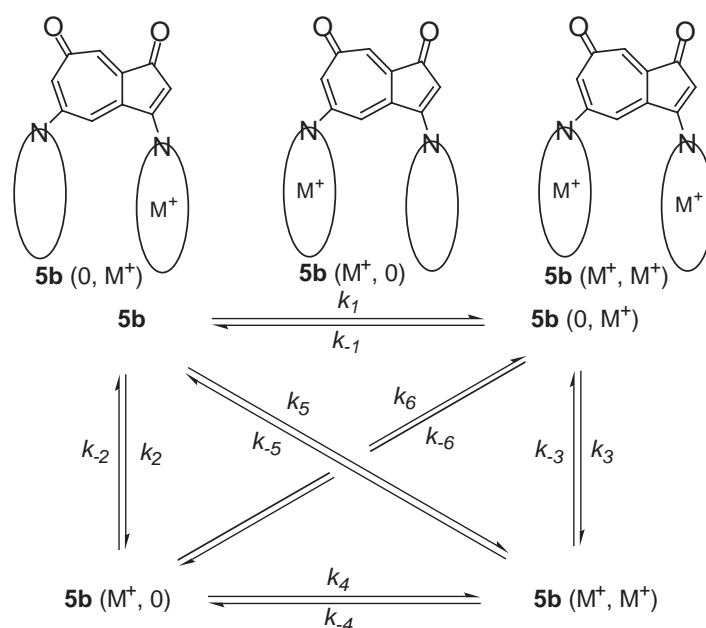
Scheme 1 Corelation diagram of complexation of **5b** and a metal ion and intramolecular metal ion exchange. The complex in which a metal ion bound by the crown part of 5- or 7-membered ring is designated as **5b** (0, M⁺) or **5b** (M⁺, 0) respectively and two metal ions bound by both crown parts is defined as **5b** (M⁺, M⁺).
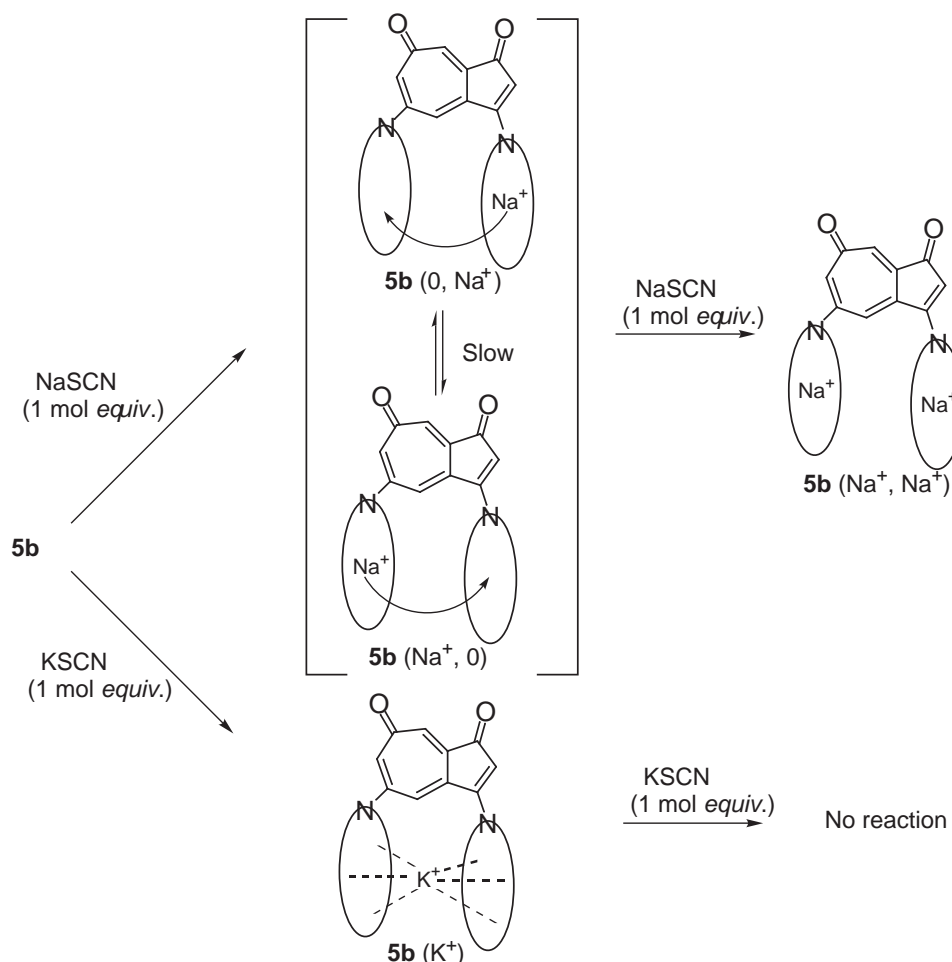
Scheme 2 Feasible mechanisms for the formation of **5b**-metal complexes in the presence of Na⁺ or K⁺.

and 2). Although several equilibriums are conceivable between those complexes, the reason why the particular equilibrium for **5b** was observed would be (1) the rates of exchange (k_1 k_5, k_{-1} k_{-5}) other than that of **5b** (0, M⁺) $\rightleftharpoons$ **5b** (M⁺, 0) (k_6, k_{-6}) are beyond time scale of NMR measurement and/or (2) **5b** (0,

M^+) and **5b** (M^+, 0) have the almost same stability (from the areal analysis of signals) and are more stable than other species. In the cases of complexes of **2**, **3**, **4** and **5a** the similar equilibrium relation to that of **5b** was not recognized at the temperature range 293　323K but only the time averaged and relatively simple signals were observed, indicating inadequacy of adopting the reason (2). Thus the singular behavior of **5b** in the presence of one molar equivalent of sodium ion might mainly depend on the reason (1). Although the intermolecular metal ion exchange such as 2[**5b** (0, M^+)] $\rightleftharpoons$ **5b** (0, M^+) + **5b** (M^+, 0) $\rightleftharpoons$ 2[**5b** (M^+, 0)] $\rightleftharpoons$ **5b** + **5b** (M^+, M^+) could be also possible, the influence from those equilibriums must be small in consideration of the concentration of the solution (10^{-2} M) and it is reasonable to think that the intramolecular metal exchange process, **5b** (0, Na^+) $\rightleftharpoons$ **5b** (Na^+, 0), is predominant in this case. Because of structural character between crown moieties, sodium cation could not stay at one crown moiety and might move slowly from one crown moiety to another. We call this movement *play catch*. Indeed we obtained the Gibbs free energy change of 65.5 kJ by measurement of variable temperature ^{1}H NMR spectra (**Tc** = 313 K). When further 1 mol *equiv.* of sodium cation is added, two cations are coordinated to each azacrown moiety respectively to form **5b** (Na^+, Na^+), and as the result an apparently single ^{1}H NMR spectrum appears. When 1 mol or 2 mol *equiv.* of potassium thiocyanate was added to **5b**, each spectral pattern changed little. This could be explained by assuming that potassium ion is sandwiched between two crown moieties to form **5b** (K^+).

Although the potassium sandwiched conformation has been found about ferrocene-based bisbenzocrown,[9] the unique phenomenon such as *play catch* between **5b** and a sodium ion is, so far as we know, new.

EXPERIMENTAL

Mps were determined with a Mitamura air-bath apparatus and are uncorrected. ^{1}H and ^{13}C NMR spectra ($SiMe_4$ as the internal standard) were determined with Bruker AC-200, AM-400 and/or ARX-400 spectrometers. IR spectra were determined with a Perkin Elmer System 2000 FT instrument and electronic spectra (UV-VIS) with a JASCO V-560 spectrophotometer. MS spectra were determined with Shimazu QP-1000 and JEOL JMS-DX 303 spectrometers. Unless otherwise stated the spectra were taken in the following solvents/media: IR, KBr; UV-VIS, CH_2Cl_2; ^{1}H (200 and 400 MHz) and ^{13}C (100 MHz) NMR, $CDCl_3$; MS spectra were taken at 70 eV by electron impact method. The progress of most reactions was followed by TLC using Merck Kieselgel $60F_{254}$.

Typical experimental procedure for the syntheses of monoazacrown-azulenequinones (2) or (3): A solution of **1** (0.16 mmol) and 3 mol *equiv.* of azacrown ether (1-aza-15-crown-5 or 1-aza-18-crown-6) in dry THF (20 mL, commercially available dehydrated solvent) was stirred at rt for 2-23 h. The reaction mixture was purified by silica gel column chromatography (eluted by EtOAc, EtOH and MeOH successively) and then recrystallized from EtOAc to give monoazacrown-AzQs (**2**) or (**3**).

Typical experimental procedure for the syntheses of bisazacrown-azulenequinones (4) or (5): A solution of **1** (0.16 mmol) and 20 mol *equiv.* of azacrown ether (1-aza-15-crown-5 or 1-aza-18-crown-6) in *abs*. EtOH (20 mL, commercially available dehydrated solvent) was stirred at rt for 17-44 h. The reaction mixture was purified twice with silica gel column chromatography (eluted by EtOH and MeOH successively) and then recrystallized from EtOAc or EtOAc-hexane to give bisazacrown-AzQs

(**4**) or (**5**).

Typical ^{1}H NMR measurement for 3,5-bis(aza-18-crown-6)-1,7-azulenequinone (5b) in the presence of sodium or potassium salt: To a solution of **5b** in acetonitrile-d$_3$ (1 x 10^{-2} M) was added 1 mol *equiv.* of NaSCN or KSCN and the reaction mixture was stood for one night, then its ^{1}H NMR spectrum was measured. To this sample solution 1 mol *equiv.* of NaSCN or KSCN was added further and it was measured after one night.

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