Cyclohepta[*b*][1,4]benzothiazines and Their Diazine Analogues. 2. Formation and Properties of Cyclohepta[*b*]quinoxalines[1,2]

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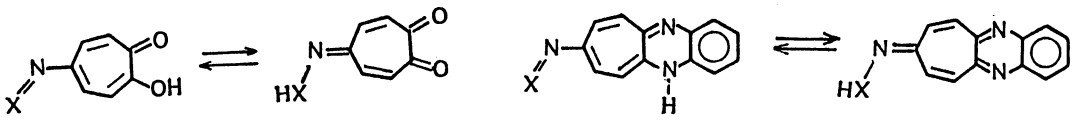
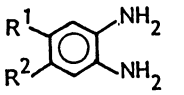
2-Chloro- or 2-methoxytropone reacts with *o*-phenylenediamine to give 2-(*o*-aminoanilino)tropone, which upon heating provides 6*H*-cyclohepta[*b*]quinoxaline (**10a**). Upon acidification, **10a** reversibly gives a green cation, **9a**. **10a** is easily converted, especially under basic conditions, into the oxidative dimer **16a**, which reproduces **9a** by reduction with Zn in acetic acid. The isopropyl derivatives of these compounds are prepared by the same method from 5-isopropyl-2-methoxytropone. The 5-methyl (**21a**) and 5,11-dimethyl derivatives **23** are made by the reaction of 2-chloro- or 2-methoxytropone with *N*-methyl- and *N,N'*-dimethyl-*o*-phenylenediamines. However, the methylation of **21a** with methyl fluorosulfate affords 5,11-dihydro-8,11-dimethyl-6*H*-cyclohepta[*b*]quinoxaline-5,6-sultone. H_2O_2 oxidation of **10a** mainly gives **16a** in addition to a small quantity of 6*H*-cyclohepta[*b*]quinoxalin-6-one. Compound **21a** is stable under basic conditions, but **23** rearranges under alkaline conditions to give, among other unidentified products, *N*-methyl-*N*-[*o*-(methylamino)phenyl]benzamide and 5,10-dihydro-5,10-dimethyl-2-phenazinecarbaldehyde. Reactions of title compounds with alkali and hydrogen peroxide are compared with those of *O*- and *S*-analogues.

One of the authors (T.N.) and his co-workers reported about thirty years ago that reactions of 5-nitroso- and 5-arylazotropolone (**1a,b**) with *o*-phenylenediamine (**2a**) gave quinoxaline derivatives (**3a,b**), which were considered to have quinonoid structures.[3] They subsequently found[4] that the reactions of 2-chloro- and 2-methoxytropone (**4a,b**) with **2a** afforded pale-violet crystals **A**, which, on catalytic reduction, produced **6a** and **7a** almost quantitatively.[4,5] They presumed that **A** was 5*H*-cyclohepta[*b*]quinoxaline (**5a**), which they named "benzo[*b*]tropazine."[4] However, they could not determine the position of the H-atom of **5a,b**, because NMR spectroscopy was not available at that time. Furthermore, they found that the reaction of 3-carboxytropolone (**4c**) with *o*-phenylenediamine (**2a**) and its methyl homologue (**2b**) produced **A** and its methyl derivative **B**, respectively. The former gave **6a** and **7a**, and the latter afforded their respective methyl derivatives (**6b** and **7b**) upon catalytic reduction. They attempted to purify the colored

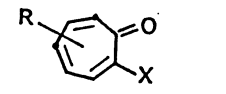


1a : X=O
b : X=NAr

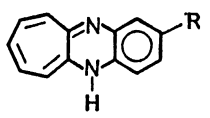
3a : X=O
b : X=NAr



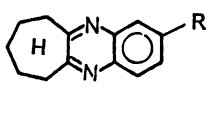
2	R^1	R^2
a	H	H
b	Me	H
c	Me	Me



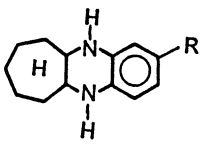
4	X	R
a	Cl	H
b	OMe	H
c	OH	3-COOH
d	OMe	5-i-Pr



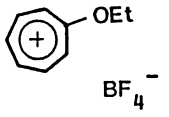
5a : R=H
b : R=Me



6a : R=H
b : R=Me



7a : R=H
b : R=Me



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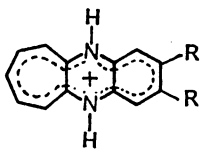
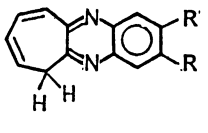


9a : R=H
c : R=Me

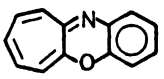


10a : R=H
c : R=Me

product **A** by using an alumina column chromatography and obtained colorless crystals **C** that were sparingly soluble in the usual organic solvents. They then considered that **C** was pure "benzo[*b*]tropazine" (**5a**).

In 1971, Fukunaga reported[5] that the reaction of ethoxytropylium tetrafluoroborate (**8**) with *o*-phenylenediamine (**2a**) and its dimethyl derivative (**2c**) gave greenish-black crystals **9a,c**, which upon basification produced neutral species **10a,c** that reverted to **9a,c** quantitatively upon acidification.[5] He believed that the structure of **10** was the quinoxaline form, and **9** existed as a resonance-stabilized (aromatic) peripheral 16 π electron system on the evidence of detailed NMR studies. He also recognized that **10** was easily dimerized oxidatively during alumina chromatography and suggested that the colorless product **C** obtained by Nozoe[4] was an oxidative dimer derived from **10a**; however, its structure was not studied.[5]

Recently, we reported in detail on cyclohepta[*b*]-[1,4]benzoxazine (**11**)[6] and its *S*-analogue (**12**);[7] we also reexamined previous studies on "benzo[*b*]tropazine"[4] because before-mentioned Fukunaga's research[5] has remained unpublished. In this report we wish to describe the detailed study on reactions of the reactive troponoids **4a,b,d** with *o*-phenylenediamine (**2a**) and its derivatives (**20a,b**).



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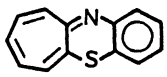

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Results and Discussion

We first observed the reaction of **4a** with **2a** in EtOH by using time-dependent HPLC by the same method as in the case of the *S*-analogues.[8] It was found that

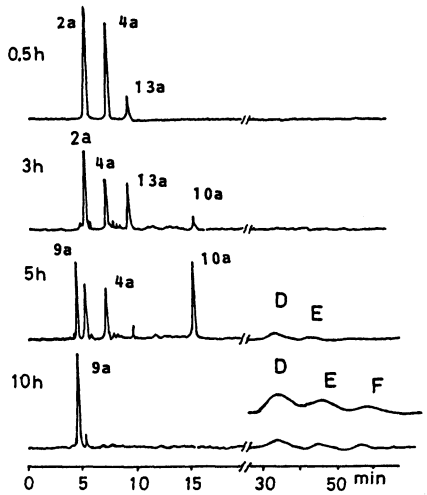


Fig. 1. Time-dependent HPLC chromatograms of the reaction mixture of **4a** with **2a** in EtOH at 80 °C.

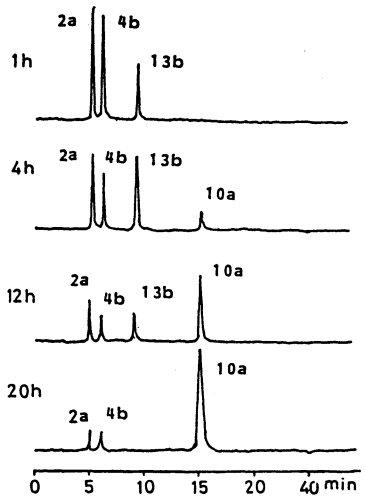


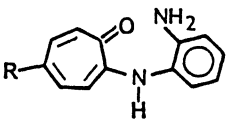
Fig. 2. Time-dependent HPLC chromatograms of the reaction mixture of **4b** with **2a** in EtOH at 80 °C.

2-(*o*-aminoanilino)tropone (**13a**) formed at an early stage of the reaction was gradually transformed into **10a** and highly polar **9a**. Finally, **13a** and **10a** almost disappeared; in addition to the main peak of polar **9a**, broad peaks with retention time (RT) 32 min (**D**), 44 min (**E**), and 57 min (**F**) appeared (see Fig. 1).

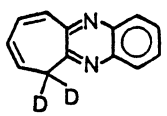
A similar reaction of **4b** with **2a** under nitrogen looked very simple chromatographically, giving **13a** and **10a** in good yields without the formation of **9a** and **D**, **E** (Fig. 2).

Compound **13a**, obtained as yellow needles, mp 183 °C, by the reaction of **4b** with **2a** in a sealed tube at 80 °C, was identified as 2-(*o*-aminoanilino)tropone on the basis of its IR, UV, NMR, and mass spectra, as well as elemental analysis; for assignments of the spectral signals, see the Experimental section. Upon further heating at 120 °C in a sealed tube, **13a** gave the dehydrated product as pale-yellow needles mp 69 °C, *m/z* 194 (M^+). This product was confirmed spectroscopically to exist in the quinoxaline form **10a**;[5] a methylene proton signal appeared at δ 3.59 (NMR), NH absorption was not seen in the IR and NMR spectra, and there was no absorption in the visible region.

Although the exitence of the tautomeric form **5a** ("benzo[*b*]tropazine") could not be detected spectroscopically, upon treatment of **10a** with MeOH-d_4 and a small amount of triethylamine at 40 °C, the H_2-6 signal gradually disappeared, presumably giving rise to the formation of deuterio compound **14** via "enamine" form **5a**.



13a : R=H
b : R=i-Pr



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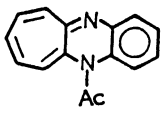

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When **10a** (RT, 15 min) was heated in acetic anhydride containing a small amount of 1,4-diazabicyclo-[2.2.2]octane (Dabco) under nitrogen, we could observe (in the HPLC diagram) a new peak (RT, 12 min), having UV absorption maxima at 225, 253, and 385 nm and m/z 236 (M^+) corresponding to the *N*-acetyl derivative **15**; the exact structure of **15**, however, could not be confirmed because of its instability.

On acidification of both **13a** and **10a** were converted into a dark-green salt **9a**, which showed considerably long-wavelength absorption bands at 564, 616, 670, and 752 nm ($\log \varepsilon$ 3.01, 2.91, 2.83, and 2.34), in addition to the three intense absorption bands (449, 464, and 491 nm) in the visible region (Fig. 3). The ^{1}H NMR spectrum of **9a** consisted of five 2H signals and a 1H signal (at δ 6.04, t, J=9.5 Hz, H-8), indicating a symmetric structure. Neutralizing of **9a** with alkali under nitrogen gave **10a** quantitatively, however, an oxidative dimeric product **16a** was gradually formed by the same treatment under aerobic conditions. Compound **16a** was also formed when **10a** was passed through an alumina column[5] or underwent heating in EtOH (in this case, giving rise to two other products **E** and **F**, presumably oxidative oligomers of **10a** as well.) When **9a** and **10a** were (separately) treated with a base in open air, the former produced **16a** much faster than the latter, suggesting that **16a** was formed by the dimerization of radical **17**, that may be more readily derived from the diazinium form **9a** than from the 6*H*-cyclohepta[*b*]quinoxaline form **10a** (Scheme 1). Compound **16a** showed a UV spectrum similar to that of **10a**. The ^{1}H NMR spectrum of **16a** closely resembled that of **10a**, with the exception of the presence of a methine proton signal at δ 4.59 (instead of the H_2-6 signal of **10a** at δ 3.59), indicating also a symmetric structure. In the mass spectrum there are no fragment peaks between m/z 386 (M^+) and m/z 193 (M^+—193); we could therefore conclude that **16a** is the dehydro dimer (2H less in mass) of **10a**. Reduction of **16a** with Zn in AcOH was found to reproduce **9a** quantitatively. Heating of **16a** at 220 °C under vacuum gave **10a** and a reddish-brown substance, the latter being presumed a fulvalene derivative **19** on the basis of mass spectrometry [m/z 384 (M^+)] and UV spectrum; carbene **18** formed by disproportionation of radical **17** is suggested as the most likely intermediate to give **19** (Scheme 1). From the experimental evidence described so far, we now consider that colorless crystals **C**[4] must have been the dimer **16a**, as speculated by Fukunaga.[5] Further, the soluble, slightly colored substace used for the catalytic reduction[4] to give **6a** and **7a** was in fact pure **10a**, because our experimental results appear to be compatible with the Fukunaga's structures **9a** and **10a**[5] (except for their electronic structure).[9]

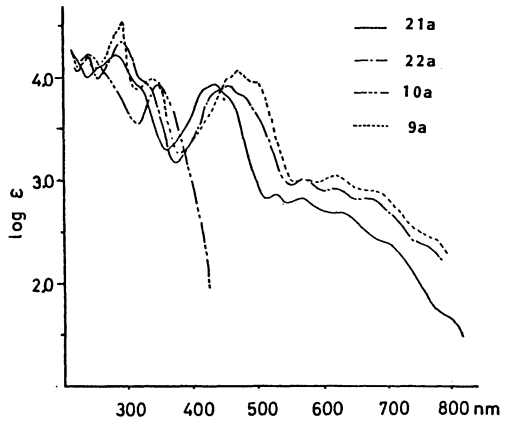
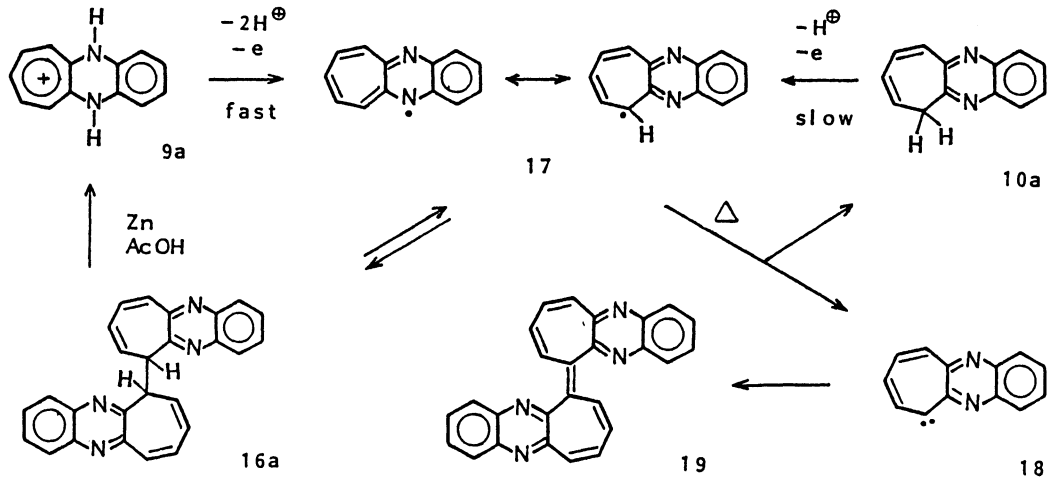


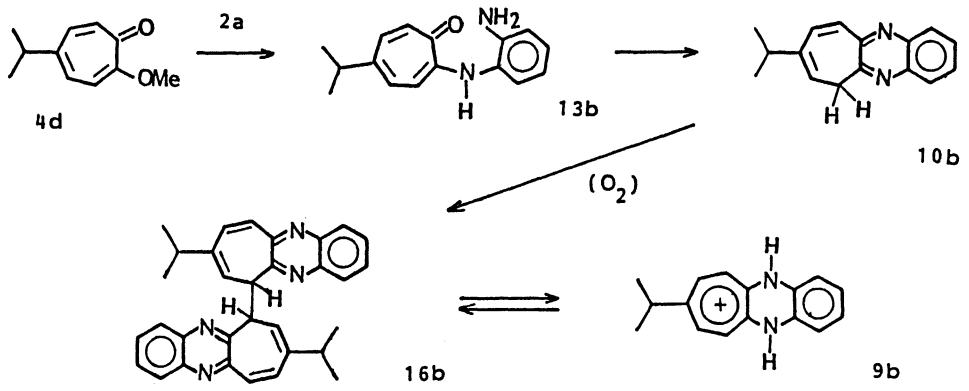
Fig. 3. Electronic spectra of some cyclohepta[*b*]quinoxalines in MeOH.

To make sure the characteristics of cyclohepta[*b*]-quinoxaline system, we also studied the isopropyl derivatives (**9b** and **10b**) prepared from 5-isopropyl-2-methoxytropone (**4d**) and **2a**, and we obtained a similar dimer **16b** reversibly from **9b**, as illustrated in Scheme 2.

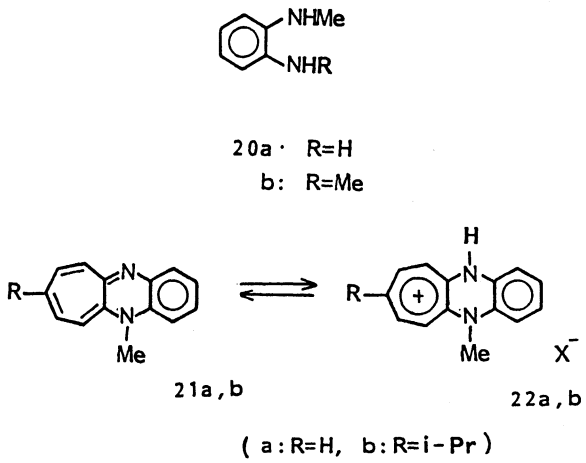
We then tried to synthesize the *N*-methyl derivative **21a** (of **5a**), which can not take the tautomeric, qui-



Scheme 1.



Scheme 2.

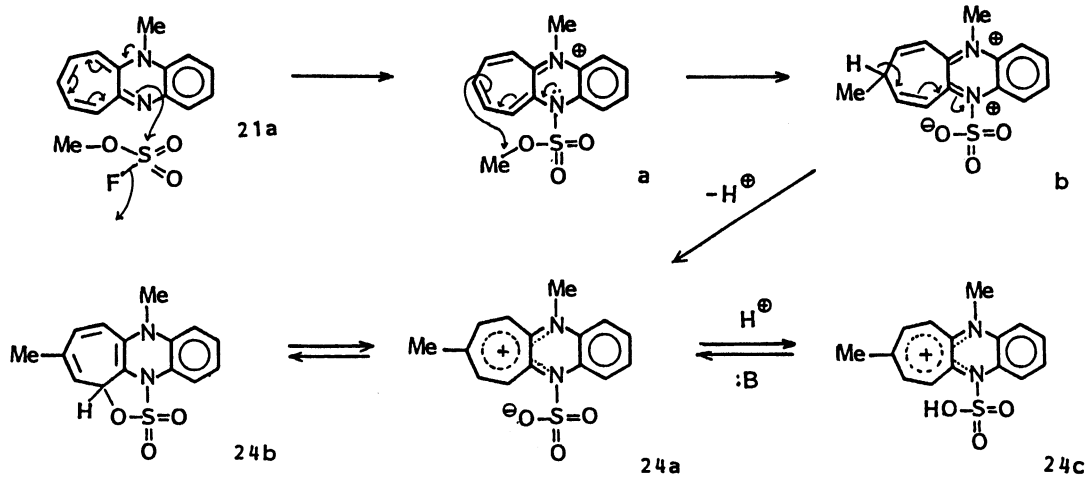


noxalo form, in order to compare its properties with those of the *O*- and *S*-analogues (**11**, **12**). Thus, *N*-methyl-5*H*-cyclohepta[*b*]quinoxaline (**21a**) was obtained as green needles having a low melting point (mp 68 °C), by the reaction of **4b** with *N*-methyl-*o*-phenylenediamine (**20a**). The structure of **21a** was established on the basis of the spectral data. It showed ^{1}H NMR signals at δ 2.67 (*N*-methyl), and at δ 4.47 (H-6) and 6.24 (H-4) due to two peri-protons; these were assigned on the basis of NOE experiment. It is worth noticing that the free *N*-methyl compound **21a** and its protonated cation **22a** have the same deep green color and are similar to **9a** in terms of the UV/VIS and ^{1}H NMR spectra, indicating that these compounds have a similar π-electron system.[9] We also prepared 8-isopropyl compound **21b** and its salt **22b** from methyl ether of γ-thujaplicin (5-isopropyltropolone).

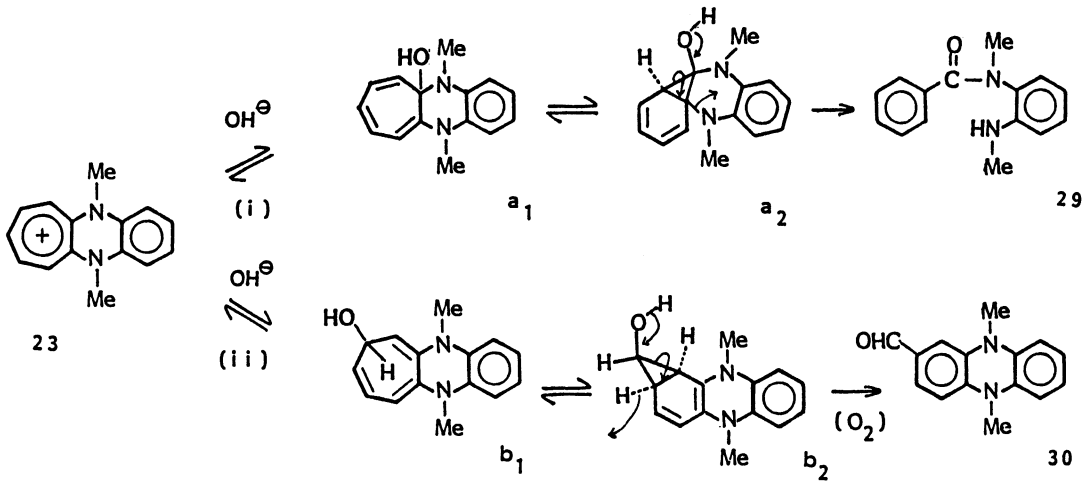
N,N'-Dimethyl cation (**23**) was obtained as dark-greenish needles (chloride and BF_4^- salts) by heating **4a** or **4b** with *N,N'*-dimethyl-*o*-phenylenediamine (**20b**) at 120 °C in the presence of acid.[2] The long-wavelength absorptions at 578, 620, and 732 nm (log ε 3.07, 3.05, and 2.56) of **23** in MeOH are similar to those of **9a** and **22a** (Fig. 3). These bands disappear in alkali and exhibit only UV maxima of an unidentified conjugate base at 230, 250, 280, and 354 nm (they are restored upon acidification). The symmetrical structure of **23** was confirmed by the NMR spectrum, which showed two methyl signals at δ 3.10 (well-resolved), three signals at δ 6.25, 6.57, and 7.24 (ratio 2 : 1 : 2) due to the seven-membered ring protons, and signals of A_2 B_2 type at δ 6.71 and 6.95 due to benzene ring protons.

We then attempted to obtain compound **23** by the treatment of **21a** with "magic methyl," which, however, resulted in the formation of green needles **24**, mp 127—128.5 °C, which had a molecular composition of $C_{15}H_{14}N_2O_3S$ (gaining a methyl and an SO_3 groups) and showed characteristic IR absorptions (KBr) at 1340 and 1160 cm^{-1} (-SO_2-). This product exhibited visible absorption at 616, 676, and 680 nm in MeOH, but in hexane the longest-wavelength absorption was at 434 nm; the absorption maxima in MeOH shifted to slightly longer wavelengths in the presence of acid. ^{1}H NMR signals in benzene-d_6 appeared at δ 1.63 and 3.29 due to two methyl protons and at δ 3.33 due to a methine proton in addition to seven olefinic proton signals, thus showing that **24** would preferably exist in the form of the intramolecular conjugate base form, 5,10-dihydro-8,11-dimethyl-6*H*-cyclohepta[*b*]quinoxaline-5,6-sultone (**24b**) in nonpolar aprotic solvent. However, the H-6, H-1, and Me-8 proton signals of **24** shifted downfield (1 ppm) in CD_3CN from those in benzene-d_6 and the spectral pattern became rather similar to that of **21a**, thus indicating that **24** is more likely to exist in another tautomeric form **24a** predominantly in a polar solvent and in a solid as well. On the other hand, in acidic methanol, the spectrum of **24b** closely resembled those of cyclohepta[*b*]quinoxalinium salts **9a** and **22**, suggesting the cationic form **24c** in acid. It should be noted that methylation with magic methyl takes place at the seven-membered ring of **21a** to give **24**; this differs from the case of methylation of *O*- and *S*-analogues (**11** and **12**) with magic methyl,[8] and also from the result of methylation of **21a** with methyl iodide.[10] Although the mechanism of this unusual reaction has not been clarified yet, one of the possible pathways is shown in Scheme 3.

A comparison is now made between the reactivities of 5*H*-cyclohepta[*b*]quinoxaline (**21** and **23**) and those of *O*- and *S*-analogues (**11** and **12**) and their respective

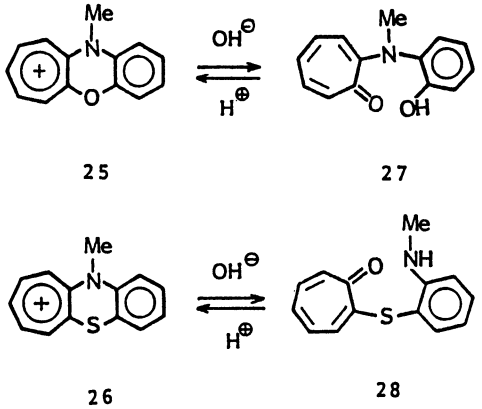


Scheme 3.

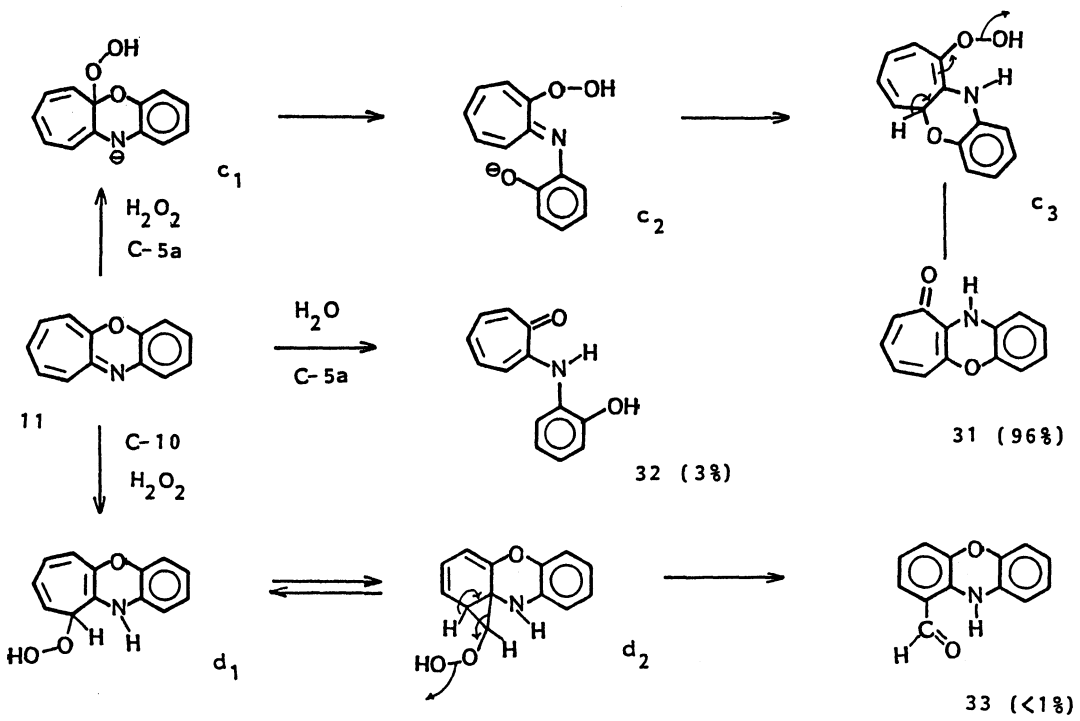


Scheme 4.

N-methylated cations (**25** and **26**). Facile ring opening by alkali and ring closure by acid is one of the characteristics of cyclohepta[*b*][1,4]benzoxazine **11** and its derivatives.[6] In paticular, *N*-methyl derivative **25** is readily saponified to 2-(*N*-methyl-*o*-hydroxyanilino)-tropone **27** (even with water at room temperature), by the attack of hydroxide ion at C-5a. Although *S*-analogue **12** is stable to warm alkali, its *N*-methyl cation **26** is saponified with cold alkali to give 2-[*o*-(methylamino)phenylthio]tropone **28** by an attack of the hydroxide ion at C-10a.[8]



On the contrary, 5-methyl-5*H*-cyclohepta[*b*]quinoxaline **21a** is quite stable to warm alkali, whereas its *N,N'*-dimethyl cation **23a** give a colorless conjugate base by dilute alkali, but is restored to **23a** upon acidification. When a methanolic solution of **23a** containing 5 equiv of sodium hydroxide was allowed to stand overnight at room temperature, various products were formed (accompanied by autoxidation), from which a 6.5% yield of 5,10-dihydro-5,10-dimethyl-2-phenazinecarbaldehyde (**30**)[12] and 11% of benzamide **29** were isolated. Possible pathways for the formation of these compounds are shown in Scheme 4. It is considered that in path (i), intermediate $\mathbf{a}_1$, produced by the attack of a hydroxide anion at C-5 of **23**, gives **29** via norcaradiene $\mathbf{a}_2$ as illustrated in the scheme, whereas in path (ii) intermediate $\mathbf{b}_1$, produced by the attack of a hydroxide anion at C-7, aromatizes to **30** via $\mathbf{b}_2$ by autoxidation. In concentrated methanolic alkali, however, **23** rearranges to benzamide **29** in 89% yield.

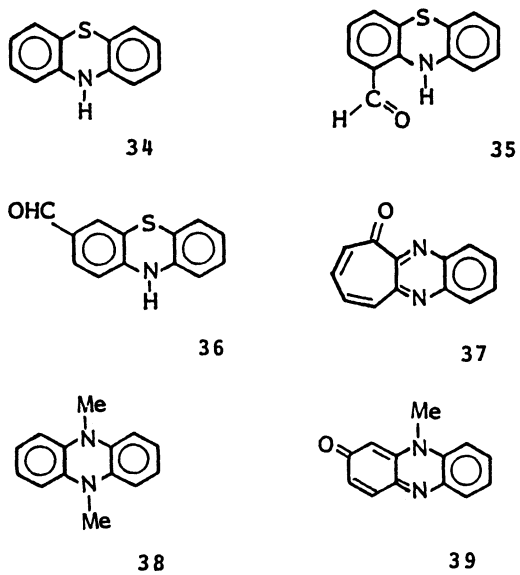


Scheme 5.

We then examined the reaction of **10a** (or **9a**) with hydrogen peroxide for a comparison with the behavior of the H_2O_2 to *O*- and *S*-analogues (**11**,[6] **12**[7,8]). Our previous findings may be summerized as follows: (1) Treatment of *O*-analogue **11** with H_2O_2 in MeOH gave almost exclusively (96%) cyclohepta[*b*][1,4]benzoxazin-10(11*H*)-one (**31**) and 2—3% of the hydrolyzed product **32**, along with a small proportion (<1%) of 1-formyl-10*H*-phenoxazine (**33**); for the reaction pathways, see Scheme 5. (2) The *S*-analogue **12** reacted[8] with H_2O_2 in MeOH slightly more slowly than **11**, producing many kinds of rearranged products, 10*H*-phenothiazine (**34**), its 1- and 3-formyl derivatives (**35**, **36**).

On the other hand, oxidation of **10a** with H_2O_2 in acetic acid gave mainly the dehydro dimer **16a** mentioned above and a small quantity of **E**, **F**, and 6*H*-cyclohepta[*b*]quinoxalin-6-one (**37**).[13] Compound **21a** is stable under basic conditions and also to H_2O_2 in MeOH at room temperature; upon heating at 60 °C, however, it was gradually oxidized to a complex mixture of products. One of them was separated as a reddish oil, which was identified spectroscopically as 10-methyl-2(10*H*)-phenazinone (**39**).[14] It was considered that **39** was formed by the oxidation of 5,10-dihydro-5-methylphenazine (**38**), derived from an oxidative rearrangement of **21a**, because phenothiazines usually form quinone derivatives upon radical oxidation.[15]

It is interesting to note that cyclohepta[*b*][1,4]benzoxazine (**11**), its *S*-analogue **12**, and *N*-analogues **10**, **21** have considerable different chemical properties. These compounds can be regarded as π-excessive heteroaromatics[16] fused with benzene and cycloheptatriene rings. Therefore, the diversity of these reactivities could be explained in terms of the electronegativity and porarizability of the hetero atoms as well as the nature of the attaching reagents. However, detailed studies (including theoretical calculations) on the π-electron system of cyclohepta[*b*]quinoxalines and those *O*- and *S*-analogues in relation to their chemical properties are currently in progress, and the results will be reported in a future paper.[17]



Experimental

Melting points were determined with a Yanagimoto MP-

3S apparatus and are uncorrected. The IR spectra were taken on a Shimadzu IR-400 or IR-450, and the UV spectra were recorded with a Shimadzu UV-202 or a Hitachi 557 spectrometer. The NMR spectra were recorded with JEOL JNM-PS100 (100-MHz) and GX270 (270-MHz) spectrometers using TMS as the internal standard. The mass spectra were taken on Shimadzu LKB9000 and JEOL JMS-01SG mass spectrometers. The HPLC was carried out on Hitachi gel #3011 with MeOH–hexane (9 : 1) as the solvent. The UV spectra in acid and alkali were taken after adding a drop of 3 M HCl or 3 M NaOH (1 M=1 mol dm^{-3}) to the sample solution. TLC analyses were carried out with Merck Kieselgel 60F-254 and Aluminium oxide F-254 plates.

Reaction of 2-Methoxytropone (4b) with *o*-Phenylenediamine (2a). A solution of **4b** (250 mg, 1.84 mmol) and **2a** (240 mg, 2.22 mmol) in EtOH (5 cm^3) was heated in a sealed tube for 6 h at 80 °C and then the solution was set aside at room temperature, depositing crystals after several hours. The precipitates were filtered off, giving **13a** (238 mg, 61%, combined with second crop). Compound **10a** (37 mg, 10%) and unreacted **4b** (56 mg, 22%) were isolated by preparative HPLC.

Heating of an ethanolic solution of **13a** in a sealed tube at 120 °C for 6 h gave a quantitative yield of **10a**.

2-(*o*-Aminophenylamino)tropone (13a): Yellow needles (from EtOH), mp 183—183.5 °C; UV (MeOH) λ_{max} 235, 338, and 401 nm (log ε 4.45, 4.00, and 4.10), (MeOH+HCl) 236, 280, 289, 333, 345, 439, 464, and 490 nm (log ε 4.22, 4.41, 4.52, 3.95, 3.92, 3.92, 4.04, and 3.90); IR (KBr) 3460, 3320 (NH_2), 3240 (NH), and 1620 cm^{-1} (C=O); ^{1}H NMR ($CDCl_3$) δ=3.75 (2H, br, NH_2), 6.64 (1H, dd, J=10.3 and 1.0 Hz, H-7), 6.75—7.46 (9H, m, ar-H), and 8.33 (1H, br, NH); MS, m/z 212 (M^+).

Anal. ($C_{13}H_{12}N_2O$) C, H, N.

***6H*-Cyclohepta[*b*]quinoxaline (10a):** Pale yellow needles (from $CHCl_3$); mp 68—69 °C; UV (MeOH) λ_{max} 235, 243, and 342 nm (log ε 4.21, 4.21, and 3.94), (MeOH+HCl) 238, 280, 289, 333, 345, 449, 464, and 491 nm (log ε 4.21, 4.34, 4.42, 3.92, 3.90, 3.79, 3.91, and 3.79), (MeOH+NaOH) 231, 247, 270, 349, and 392 nm (log ε 4.27, 4.26, 4.17, 3.94, and 3.48); ^{1}H NMR (CD_3 CN) δ=3.59 (2H, d, J=5.8 Hz, CH_2), 6.08 (1H, dt, J=10.3 and 5.8 Hz, H-7), 6.28 (1H, dd, J=10.3 and 5.3 Hz, H-8), 6.80 (1H, dd, J=11.7 and 5.3 Hz, H-9), 7.71 (2H, m, H-2,3), 7.28 (1H, d, J=11.7 Hz, H-10) and 8.05 (2H, m, H-1,4); MS, m/z 194 (M^+).

Anal. ($C_{13}H_{10}N_2$) C, H, N.

Reaction of 5-Isopropyl-2-methoxytropone (4d) with 2a. Reaction of **4d** (200 mg, 1.12 mmol) with **2a** (145 mg, 1.34 mmol) as described above gave **13b** (153 mg, 54%), **10b** (18 mg, 7%) and unreacted **4d** (54 mg, 27%).

Heating of **13b** (100 mg, 0.39 mmol) as described for **13a** (see above) gave **10b** (73 mg, 79%) and unreacted **13b** (27 mg, 27%).

2-(*o*-Aminoanilino)-5-isopropyltropone (13b): Yellow needles (from EtOH); mp 155—156 °C; UV (MeOH) λ_{max} 236, 341, and 405 nm (MeOH+HCl) 236, 283, 291, 334, 347, 448, 471, and 500 nm; ^{1}H NMR ($CDCl_3$) δ=1.20 (6H, d, J=6.8 Hz, $2CH_3$), 2.79 (1H, sept, J=6.8 Hz, CH), 3.77 (2H, br, NH_2), 6.57 (1H, d, J=10.3 Hz, H-7), 6.78—7.28 (7H, m, ar-H), and 8.14 (1H, br, NH); MS, m/z 254 (M^+).

Anal. ($C_{16}H_{18}N_2O$) C, H, N.

8-Isopropyl-6*H*-cyclohepta[*b*]quinoxaline (10b): Pale yellow oil; UV (MeOH) λ_{max} 213, 247, and 340 nm (MeOH+HCl) 215, 249, 292, 340, and 468 nm ; ^{1}H NMR ($CDCl_3$) δ=1.05 (6H, d, J=6.8 Hz, $2CH_3$), 2.48 (1H, sept, J=6.8 Hz, CH), 3.51 (2H, d, J=6.3 Hz, CH_2), 5.81 (1H, t, J=6.3 Hz, H-7), 7.72 (1H, d, J=12.2 Hz, H-9), 7.71 (2H, m, H-2,3), 7.80 (1H, d, J=12.2 Hz, H-10), and 8.03 (2H, m, H-1,4); MS, m/z 236 (M^+).

Anal. ($C_{16}H_{16}N_2$) C, H, N.

***5H*-Cyclohepta[*b*]quinoxalinium Salts (9a).** A solution of **10a** (100 mg, 0.52 mmol) in EtOH (2 cm^3) was treated with various acids (1 : 2); the mixture was set aside at room temperature, depositing crystals. The precipitates were filtered off, giving **9a** (BF_4^- salt, 121 mg, 85%) as dark green needles. BF_4^- salt: mp 227.2—229 °C; UV (MeOH) λ_{max} 236, 279sh, 289, 331, 445, 449sh, 464, and 481sh (log ε 4.16, 4.37, 4.46, 3.89, 3.84, 3.96, 4.00, and 3.94), (MeOH+NaOH) 231, 246, 347, and 391 (log ε 4.24, 4.22, 3.85, and 3.31); ^{1}H NMR (CD_3CN) δ=5.68 (2H, d, J=11.2 Hz, H-6,10), 6.04 (1H, t, J=9.5 Hz, H-8), 6.14 (2H, m, H-1,4), 6.52 (2H, m, H-2,3), 6.62 (2H, dd, J=11.2 and 9.5 Hz, H-7,9), and 7.95 (2H, br, NH).

Anal. ($C_{13}H_{11}N_2BF_4$) C, H, N.

ClO_4^- salt: mp 227—228.5 °C. CF_3COO^- salt: mp 198—199 °C. Br^- salt: mp 300 °C. Cl^- salt: mp 190—190.5 °C.

8-Isopropyl-5*H*-cyclohepta[*b*]quinoxalinium Salts (9b). Treatment of **10b** (50 mg, 0.21 mmol) with acid (as described above) gave **9b** (BF_4^- salt, 57 mg, 83%) as dark green needles. BF_4^- salt: mp 237—238 °C; UV (MeOH) λ_{max} 236, 283, 291, 338, 347, 446, 470, and 500 nm (log ε 4.18, 4.35, 4.48, 3.91, 3.83, 3.96, 4.04, and 3.87), (MeOH+NaOH) 245 and 341 nm (log ε 4.29 and 3.85); ^{1}H NMR (CD_3CN) δ=1.10 (6H, d, J=6.8 Hz, $2CH_3$), 2.39 (1H, m, J=6.8 Hz, CH), 5.71 (2H, d, J=11.5 Hz, H-6,10), 6.10 (2H, m, H-1,4), 6.48 (2H, m, H-2,3), 6.64 (2H, J=11.5 Hz, H-7,9), and 7.75 (2H, br, NH).

Found: C, 58.97; H, 5.51; N, 8.43%. Calcd for $C_{16}H_{17}N_2BF_4$: C, 59.29; H, 5.29; N, 8.64%.

ClO_4^- salt: mp 289—290 °C.

6,6′-Bi-6*H*-cyclohepta[*b*]quinoxaline (16a): Aqueous $NaHCO_3$ was slowly added to a suspension of **9a** (BF_4^- salt, 100 mg, 0.35 mmol) in EtOH (1 cm^3); the mixture was allowed to stand overnight exposed to air. The precipitates were filtered off and extracted with $CHCl_3$. The extracts were combined with the precipitates and purified by preparative HPLC, giving **16a** (57 mg, 84%, RT 32 min) as colorless plates: mp 193.5—194.5 °C (from $CHCl_3$); UV (MeOH) λ_{max} 215, 233, and 338 nm; ^{1}H NMR (270 MHz in $CDCl_3$) δ=4.59 (2H, br, H-6,6′), 6.20 (2H, d, J=10.2 Hz, H-7,7′), 6.43 (2H, dd, J=10.2 and 5.1 Hz, H-8,8′), 7.02 (1H, dd, J=11.7 and 5.1 Hz, H-9,9′), 7.40 (2H, t, J=8.1 Hz, H-3,3′ or 2,2′), 7.49 (2H, d, J=8.1 Hz, H-4,4′ or 1,1′), 7.53 (2H, t, J=8.1 Hz, H-2,2′ or 3,3′), 7.54 (2H, d, J=11.7 Hz, H-10,10′), and 7.96 (2H, d, J=8.1 Hz, H-1,1′ or 4,4′); MS, m/z 386 (M^+, 7), 294 (58), 193 (100), and 192 (30).

Anal. ($C_{26}H_{18}N_4$) C, H, N.

6,6′-Bicycloheptiden[*b*]quinoxaline (19): Heating of **16a** of 220 °C in vacuo in a sealed tube gave **10a** and **19** (observed by HPLC). **19**: reddish brown needles, mp 300 °C decomp.; MS m/z 384 (M^+, 100), 193 (6), and 191 (23); UV (Hexane-MeOH) λ_{max} 217, 249, 349, and 404 nm.

8,8′-Diisopropyl-6,6′-bi-6*H*-cyclohepta[*b*]quinoxaline (16b). Treatment of **9b** (BF_4^- salt, 50 mg, 0.15 mmol) with alkali (as described above) gave **16b** (27 mg, 74%) as pale yellow needles: mp 134—135 °C; UV (MeOH) λ_{max} 220, 244, and 336 nm; ^{1}H NMR ($CDCl_3$) δ=1.08 (6H, d, J=6.8 Hz, $2CH_3$), 1.13 (6H, d, J=6.8 Hz, $2CH_3$), 2.59 (2H, m, J=6.8 Hz, CH), 4.50 (2H, br, H-6,6′), 5.88 (2H, br, H-7,7′), 7.00 (2H, d,

J=11.7 Hz, H-9,9'), 7.39—7.61 (8H), and 7.91—8.01 (2H); MS, m/z 470 (M^+).

Anal. ($C_{32}H_{30}N_4$) C, H, N.

5-Methyl-5*H*-cyclohepta[*b*]quinoxaline (21a). A solution of **4b** (224 mg, 1.65 mmol) and *N*-methyl-*o*-phenylenediamine (**20a**) (251 mg, 2.06 mmol) in EtOH (2 cm^3) was heated in a sealed tube for 24 h at 120 °C. After removing the solvent, the residue was taken in a small amount of $CHCl_3$ and chromatographed on silica-gel thin-layer plates with acetonitrile as the eluant, giving **21a** (237 mg, 69%) as dark green needles along with unreacted **4b** (16 mg, 7%) : mp 68 °C; UV (MeOH) λ_{max} 229, 274, 324, 429, 458, 525, 568, 630, and 696 nm (log ε 4.09, 4.22, 3.87, 3.98, 3.75, 2.62, 2.61, 2.45, and 2.15), (MeOH+HCl) 237, 288, 334, 430, 451, 485, 565, 616, 670, and 752 nm (log ε 4.17, 4.33, 3.91, 3.79, 3.91, 3.76, 3.01, 2.91, 2.83, and 2.34); ^{1}H NMR (270 MHz in CD_3CN) δ=2.67 (3H, s, CH_3), 4.47 (1H, d, J=9.7 Hz, H-6), 5.22 (1H, dd, J=10.8 and 7.6 Hz, H-8), 5.40 (1H, J=12.3 Hz, H-10), 5.79 (1H, ddd, J=12.3, 7.6, and 1.5 Hz, H-9), 5.84 (1H, ddd, J=10.8, 9.7, and 1.5 Hz, H-7), 6.24 (1H, dd, J=8 and 1.5 Hz, H-4), 6.48 (1H, dd, J=8 and 1.5 Hz, H-6), 6.52 (1H, td, J=8 and 1.5 Hz, H-2), and 6.68 (1H, td, J=8 and 1.5 Hz, H-3), (250 MHz in CF_3COOD) δ=3.02 (3H, s, CH_3), 5.95 (1H, d, J=11 Hz, H-10), 6.08 (1H, d, J=11 Hz, H-10), 6.35 (1H, t, J=9 Hz, H-8), 6.37 (1H, dd, J=7.5 and 1.5 Hz, H-4), 6.51 (1H, dd, J=8 and 1.5 Hz, H-1), 6.78 (1H, td, J=8, 7.5 and 1.5 Hz, H-3), 6.88 (1H, ddd, J=11, 9 and 1.5 Hz, H-9), 6.88 (1H, td, J=8 and 1.5 Hz, H-2) and 7.01 (1H, ddd, J=11, 9, and 1.5 Hz, H-7); MS, m/z 208 (M^+).

Anal. ($C_{14}H_{12}N_2$) C, H, N.

8-Isopropyl-5-methyl-5*H*-cyclohepta[*b*]quinoxaline (21b). The reaction of **4c** and **20a** was conducted in a manner similar to that described above for **21a**, giving **21b** in 51% yield: Dark green oil; mp 200 °C (picrate); UV (MeOH) λ_{max} 228, 260, 282, 324, 432, 525, 568, 628, and 686 nm (log ε 4.19, 4.18, 4.27, 3.29, 3.99, 2.88, 2.81, 2.62, and 2.30), (MeOH+HCl) 237, 299, 332, 428, 446, 488, 564, 616, 672, and 760 nm (log ε 4.24, 4.60, 3.97, 3.88, 4.00, 3.83, 3.01, 2.99, 2.84, and 2.23); ^{1}H NMR (100 MHz in $CDCl_3$) δ=0.98 (6H, d, J=6.6 Hz, $2CH_3$), 2.09 (1H, sept, J=6.6 Hz, CH), 2.70 (3H, s, N-CH_3), 4.41 (1H, d, J=9.8 Hz, H-6), 5.47 (1H, d, J=12.5 Hz, H-9), 5.74 (1H, d, J=9.8 Hz, H-7), 6.01 (1H, d, J=12.5 Hz, H-10), 6.12 (1H, d, J=7.3 Hz, H-4), 6.61 (3H, m, H-1,2,3), (CF_3COOD) δ=1.15 (6H, d, J=7.1 Hz, $2CH_3$), 2.51 (1H, sept, J=7.1 Hz, CH), 2.98 (3H, s, N-CH_3), 5.93 (1H, d, J=12 Hz, H-6), 6.07 (1H, d, J=12 Hz, H-10), 6.30 (1H, d, J=7 Hz, H-4), 6.41 (1H, d, J=7 Hz, H-1), 6.70 (2H, m, H-2,3), 6.88 (1H, d, J= 12 Hz, H-9 or 7) and 6.98 (1H, d, J=12 Hz, H-7 or 9); MS, m/z 250 (M^+).

Anal. ($C_{17}H_{18}N_2$) C, H, N.

5,11-Dimethyl-5*H*-cyclohepta[*b*]quinoxalinium Salts (23). (a) Concd HCl (100 mg) was added to a solution of **4a** (300 mg, 2.14 mmol) and *N,N'*-dimethyl-*o*-phenylenediamine **20b** (436 mg, 3.21 mmol) in EtOH (2 cm^3); the mixture was heated in a sealed tube for 20 h at 120 °C. After cooling, the precipitates were collected, giving **23** (481 mg, 87% with the second crop). (b) The reaction of **4b** (120 mg, 0.88 mmol) with **20b** (180 mg, 1.32 mmol) and 42% HBF_4 as above gave the BF_4^- salt (106 mg, 39%). Cl^- salt: Dark green needles; mp 230 °C (from EtOH); UV (MeOH) λ_{max} 238, 287, 328, 440, 580, 620, and 630 nm. (log ε 4.18, 4.23, 3.84, 3.81, 3.07, 3.05, and 2.56); ^{1}H NMR (270 MHz in CD_3CN) δ=3.10 (6H, s, $2CH_3$), 6.25 (2H, d, J=11 Hz, H-6, 10), 6.57 (1H, t, J=9.5 Hz, H-8), 6.71 (2H, m, H-1, 4), 6.95 (2H, m, H-2, 3), and 7.24 (2H, dd, J=11.3 and 9.5 Hz, H-7,9).

Anal. ($C_{15}H_{16}N_2Cl$) C, H, N.

BF_4^- salt: Dark green needles; mp 223 °C

Reaction of 23 with NaOH. (a) Aqueous NaOH (1 g/3 cm^3 of H_2O) was added to a green solution of **23** (150 mg, 0.58 mmol) in MeOH (150 cm^3); the solution turned to colorless. After removing the solvent, the residue was extracted with $CHCl_3$. The combined extracts were concentrated and chromatographed on a silica-gel column with 10 : 1 benzene-MeOH as the eluant, giving **29** (124 mg, 89%). (b) Aqueous NaOH (80 mg/ H_2O, 0.5 cm^3) was added to a solution of **23** (100 mg, 0.39 mmol) in MeOH (100 cm^3) and the solution was set aside overnight at room temperature; it slowly became reddish brown. After removing the solvent, the residue was chromatographed on silica-gel thin-layer plates with 10 : 1 benzene-MeOH as the eluant, giving **30** (5 mg, 6.5%) besides **29** (11%) and many products.

***N*-Methyl-*N*-[*o*-(methylamino)phenyl]benzamide (29):** Colorless needles (from MeOH), mp 140 °C; MS, m/z 240 (M^+); UV (MeOH) λ_{max} 238 and 301 nm (log ε 4.19 and 3.57), (MeOH+HCl) 233, 271, and 278 nm (log ε 4.15, 4.08, and 4.14); IR (KBr) 3360 (NH) and 1630 cm^{-1} (CO); ^{1}H NMR (270 MHz in $CDCl_3$) δ=2.92 (3H, d, J=5.5 Hz, CH_3), 3.29 (3H, s, CH_3), 4.19 (1H, q, J=5.5 Hz, NH), 6.46 (1H, t, J=7.7 Hz), 6.61 (1H, d, J=8.2 Hz), 6.71 (1H, d, J=7.7 Hz), 7.12 (3H, m), 7.20 (1H, d, J=7.1 Hz) and 7.29 (2H, dd, J=7.7 and 7.1 Hz); MS, m/z 240 (M^+, 41), 163 (12), 135 (31), 120 (28), 119 (78), 106 (9), 105 (42), 91 (9), and 77 (100).

Anal. ($C_{15}H_{16}N_2O$) C, H, N.

5,10-Dihydro-5,10-dimethyl-2-phenazinecarbaldehyde (30): Reddish orange crystals; mp 83 °C (lit,[12] red plates, mp 185 °F); UV (MeOH) λ_{max} 237, 288, 351, and 432 nm (log ε 4.38, 4.37, 3.65, and 3.37), (MeOH+HCl) 241, 260, 290, 348, and 442 nm (log ε 4.36, 4.16, 4.25, 3.68, and 3.69); ^{1}H NMR (270 MHz in C_6D_6) δ=2.28 (3H, s, CH_3), 2.30 (3H, s, CH_3), 5.82 (1H, d, J=7.7 Hz, H-4), 5.99 (2H, m, H-6,9), 6.64 (2H, m, H-7,8), 6.81 (1H, d, J=1.7 Hz, H-1), and 6.89 (1H, dd, J=7.7 and 1.7 Hz, H-3); MS, m/z 238 (M^+, 77), 238 (86), 195 (100), and 180 (48).

Found: m/z 238.1113. Calcd for $C_{15}H_{14}N_2O$: M, 238.1105.

5,11-Dihydro-8,11-dimethyl-6*H*-cyclohepta[*b*]quinoxaline-5,6-sultone (24b). A solution of **21a** (100 mg, 0.96 mmol) and methyl fluorosulfate (200 mg, 1.75 mmol) in dichloromethane (0.5 cm^3) was shaken in a sealed flask for 40 h at room temperature. After removing the solvent and excess sulfate in vacuo, the residue was diluted with aqueous $NaHCO_3$ and then extracted with $CHCl_3$. The extracts were combined and concentrated in vacuo. The residue was chromatographed on silica-gel thin-layer plates with 10 : 1 benzene-MeOH as the eluant, giving **24** (178 mg, 61%) as green needles: mp 127—128.5 °C (from $CHCl_3$); UV (MeOH) λ_{max} 268, 276, 328, 443, 464, 616, 676, and 680 nm (log ε 4.43, 4.38, 4.09, 4.27, 4.22, 3.20, 3.08, 2.72) (MeOH+NaOH) 230, 250, 280, and 354 nm. (MeOH+HCl) 240, 284, 334, 432, 460, 490, 564, 622, and 684 nm (log ε 4.31, 4.45, 4.21, 4.04, 4.29, 4.30, 3.07, 3.01, 2.80), (hexane) 265, 322, and 434 nm; IR (KBr) 1160, 1340 cm^{-1} (-SO_2-); ^{1}H NMR (270 MHz in C_6D_6) δ=1.63 (3H, s, CH_3), 3.29 (3H, s, N-CH_3), 3.33 (1H, d, J=10.2 Hz, H-6), 5.49 (1H, d, J=12.8 Hz, H-10), 5.61 (1H, dt, J=9.5 and 3.3 Hz, H-1), 5.98 (1H, dd, J=12.8 and 2.2 Hz, H-9), 6.44 (1H, dd, J=10.2 and 2.2 Hz, H-7), 6.44 (2H, m, H-2,3), and 6.88 (1H, dt, J=9.5 and 3.3 Hz, H-4), (270 MHz in CD_3CN) δ=2.86 (3H, s, CH_3), 3.74 (3H, s, N-CH_3), 4.47 (1H, d, J=11.0

Hz, H-6), 5.38 (1H, d, J=13.2 Hz, H-10), 5.90 (1H, dd, J=13.2 and 2.2 Hz, H-9), 6.51 (1H, dd, J=11.0 and 2.2 Hz, H-7), 6.54 (1H, d, J=6.6 Hz, H-1), 6.69 (1H, dd, J=6.5 and 1.5 Hz, H-4), 6.74 (1H, td, J=6.5 and 1.5 Hz, H-3), 6.86 (1H, td, J=6.5 and 1.5 Hz, H-2), (270 MHz in CD_3CN+CF_3COOD) δ=2.99 (3H, s, CH_3), 3.81 (3H, s, CH_3), 5.69 (1H, d, J=11.7 Hz, H-10), 5.83 (1H, d, J=11.7 Hz, H-6), 6.56 (1H, dd, J=7.5 and 1.5 Hz, H-4), 6.71 (1H, dd, J=7.5 and 1.5 Hz, H-1), 6.87 (1H, td, J=7.5 and 1.5 Hz, H-2), 6.95 (1H, td, J=7.5 and 1.5 Hz, H-3), 7.05 (1H, dd, J=11.7 and 2.2 Hz, H-9) and 7.20 (1H, dd, J= 11.7 and 2.2 Hz, H-7); MS, m/z 302 (M^+, 100), 287 (13), 223 (13), 208 (14), 207 (38), 206 (11), 205 (12), 193 (13), 192 (23), 191 (17), and 182 (31).

Found: m/z 302.0679. Calcd for $C_{15}H_{14}N_2O_3S$: M, 302.0724.

Oxidation of 10a with H_2O_2: To a solution of **10a** (20 mg) in acetic acid (2 cm^3) was added 28% H_2O_2 (100 mg), and the mixture was set aside for 24 h at room temperature. Each product was separated and identified by means of HPLC, giving **16a** (80%), **E** and **F** (7%), and **37**[13] (5%). The yields were based on the peak areas.

Oxidation of 21a with H_2O_2: Compound **21a** (50 mg) was treated with 28% H_2O_2 (0.1 cm^3) in methanol (0.5 cm^3) at 60 °C for 70 h. Many product spots were seen on TLC, and **39** was separated (10% yield) by using preparative TLC with benzene–MeOH (10 : 1) as eluant.

10-Methyl-2(10*H*)-phenazinone (39):[14] Red solid; UV (MeOH) λ_{max} 229, 276sh, 284, 355, 512, and 550sh nm (log ε 4.69, 4.57, 4.60, 3.86, 3.83, and 3.70); ^{1}H NMR (270 MHz in $CDCl_3$) δ=7.02 (1H, s, H-1), 7.35 (1H, d, J=9 Hz, H-3), 7.64 (1H, t, J=8 Hz, H-6), 7.80 (1H, d, J=8 Hz, H-8), 7.85 (1H, d, J=9 Hz, H-4), 7.89 (1H, t, J=8 Hz, H-7), 8.19 (1H, d, J=8 Hz, H-6); MS, m/z 210 (M^+, 74), 182 (100), and 167 (29).

Found: m/z 210.0803. Calcd for $C_{13}H_{10}N_2O$: M, 210.0793.

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