Hydrobromic Acid-Dimethyl Sulfoxide Reagent for Dealkylation of 5,10-Dialkyl-5,10-dihydrophenazines: Synthesis of 10-Alkyl-2(10*H*)-phenazinones

Akira Sugimoto,* Yasuyuki Yoshino, Ryo Watanabe, and Kazuhiko Mizuno

Department of Applied Chemistry, College of Engineering, Osaka Prefecture University, 1-1, Gakuencho, Sakai, Osaka 599-8531, Japan

Kaku Uehara

Research Institute for Advanced Science and Technology, Osaka Prefecture University, 1-2, Gakuencho, Sakai, Osaka 599-8570, Japan

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By the reaction of 5,10-dialkyl-substituted 5,10-dihydrophenazine with hydrobromic acid in dimethyl sulfoxide at 90-110°, 10-alkyl-2(10*H*)-phenazinone was obtained as a major product. Brominated dihydrophenazine was isolated in the case of 1,6-dichloro-5,10-dimethyl-5,10-dihydrophenazine.

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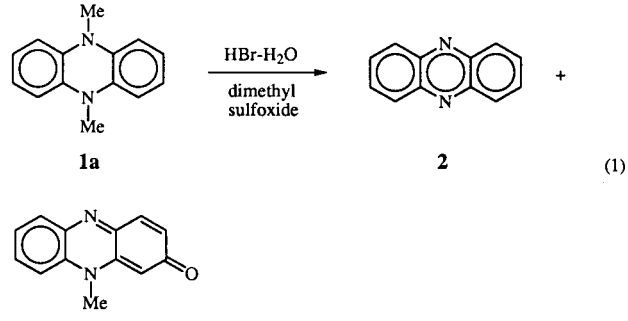
Dimethyl sulfoxide is not only a good solvent, but an oxidizing reagent in some cases. Its related reagents have been widely developed [1]. Among them, hydrobromic acid-dimethyl sulfoxide reagent, which is believed to be bromodimethyl-sulfonium bromide [2, 3], is a useful synthetic reagent. In some cases it has been used for the purpose of bromination under mild conditions [3]. In the case of 5,10-dimethyl-5,10-dihydrophenazine (**1a**), however, brominated compound was not isolated by the reaction with this reagent but **1a** changed to phenazine (**2**) *via* oxidative demethylation accompanied by a mixture of unidentified compounds [4]. Recently, one of the reaction mixture was found to be 10-methyl-2(10*H*)-phenazinone (**3a**) (equation 1). We wish to report here the novel preparative method [5] for 10-alkyl-2(10*H*)-phenazinone (**3**) by oxidation of 5,10-dialkyl-5,10-dihydrophenazines **1** with hydrobromic acid-dimethyl sulfoxide reagent [5,6].



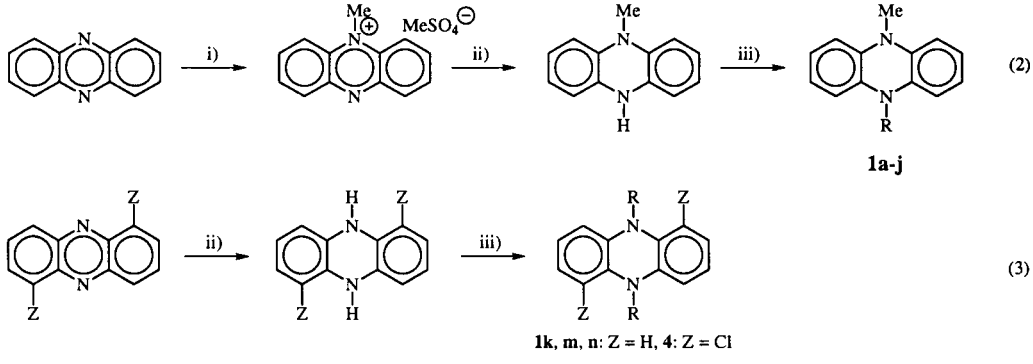
1a **2** **3a** (1)

Results and Discussion.

Starting Materials.

Dealkylations of fourteen dihydrophenazines were examined. 10-Substituted 5-methyl- **1a-j** and 5,10-disubstituted, **1k, m, n,** 5,10-dihydrophenazines and 1,6-dichloro-5,10-dimethyl-5,10-dihydrophenazine (**4**) were prepared by the similar method reported earlier [7] (equations 2 and 3) and identified by the spectroscopic data (uv, ir, ^{1}H nmr) and elemental analyses.

Reaction Conditions.



i) Me_2SO_4, ii) $Na_2S_2O_4$-H_2O, iii) BuLi, then RX

Without acid, no detectable amount of **3a** was obtained by heating of dimethyl sulfoxide solution of **1a** at 90-110° for 2 hours (Table 1), indicating that acid is indispensable for this reaction. In the presence of various acids, **1a** was heated under the same conditions. The results, shown in Table 1, indicated that the best isolated yields of **2** and **3a** were observed on the reaction with hydrobromic acid, although the yield of **3a** was poor. As the prolonged heating caused a large decrease of the yield, heating (2 hours) was adopted to obtain the best results.

Table 1

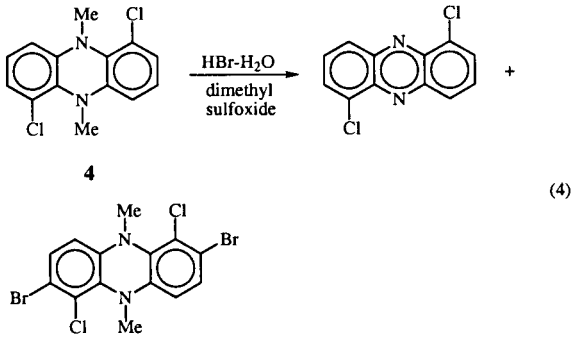
Isolated Yields of **2** and **3a** in the Presence of Various Acids

Acid	Yields / %		Recovery /%
	3a	**2**	
None	0	0	94
MeCOOH - H_2O	0	4	81
HCl - H_2O	0	34	0
HI - H_2O	6	24	30
H_2SO_4 - H_2O	4	6	46
HBr - H_2O	12	77	0
$HClO_4$ - H_2O[a]	3	16	15

[a] **CAUTION**: Addition of this acid into dimethyl sulfoxide solution of **1a** sometimes catches fire.

Reaction of **1** with Hydrobromic Acid-Dimethyl Sulfoxide Reagent.

The dihydrophenazines **1** in dimethyl sulfoxide were heated at 90-110° in the presence of an excess amount of hydrobromic acid to give the corresponding 2(10*H*)-phenazinones **3**. In some cases, **2** was obtained in the first eluent of the chromatography as the major product. These results are summarized in Table 2. In the case of **4**, however, major product was 2,7-dibromo-1,6-dichloro-5,10-dimethyl-5,10-dihydrophenazine (**5**) in 61% yield and trace amount of demethylated compound was isolated (equation 4). The corresponding phenazinone, in this case, was not obtained. Phenazine and substituted phenazines were identified by the spectrometric methods. The phenazinones, isolated by column chromatography, were also identified by their spectroscopic data and elemental analysis. Thus, ir absorption at



4 **5** (4)

Table 2

Isolated Yields of 2(10*H*)-Phenazinones **3** and Phenazine (**2**)

1	R	R' (Leaving group)	**3**	Yields, / % **3**	**2**
a	CH_3	CH_3	**a**	12	77
b	CH_3	H	**a**	17	73
c	n-C_4H_9	CH_3	**c**	72	0
d	n-$C_{12}H_{25}$	CH_3	**d**	52	0
e	n-$C_{18}H_{37}$	CH_3	**e**	65	0
f	$C_6H_5(CH_2)_3$	CH_3	**f**	65	0
g	$C_6H_5(CH_2)_2$	CH_3	**g**	79	0
h	$C_6H_5CH_2$	CH_3	**h**	25	15
i	(p-)$O_2NC_6H_4CH_2$	CH_3	**i**	28	33
j	(p-)$H_3COC_6H_4CH_2$	CH_3	**j**	0	67
k	$C_6H_5CH_2$	$C_6H_5CH_2$	**k**	36	3
m	CH_2=$CHCH_2$	CH_2=$CHCH_2$	**m**	40	28
n	(p-)$H_3COC_6H_4CH_2$	(p-)$H_3COC_6H_4CH_2$	**n**	0	72 [a]

[a] 2-Bromophenazine was isolated in 7% yield.

1624-1631 cm^{-1} due to CO double bond, uv absorption at around 520 nm, and ^1H nmr signals of AB-type at δ 7.1-8.0 and singlet at 6.3 ppm are consistent with the quinonoid structures. Furthermore, the structure of **3f** was confirmed by X-ray crystal structure analysis. The crystallographic data are shown in Tables 3-5. The ORTEP drawing of **3f**, shown in Figure 1, indicates the virtually planar shape of the phenazinone moiety. Actually, the angle between the two benzene rings of the phenazinone moiety is 2.9°. The bond angles around N1 atom are 121.3, 119.4, and 119.3° (total: 360°) as shown in Table 4, suggesting the sp^2-type hybridization of N1 atom (Figure 1). The bond distances of C2=O, C3=C4, C11=N2, and C2-C3 are 1.240, 1.322, 1.299, and 1.459 Å (Table 4), respectively. These values are reasonable ones compared with those of p-benzoquinone,

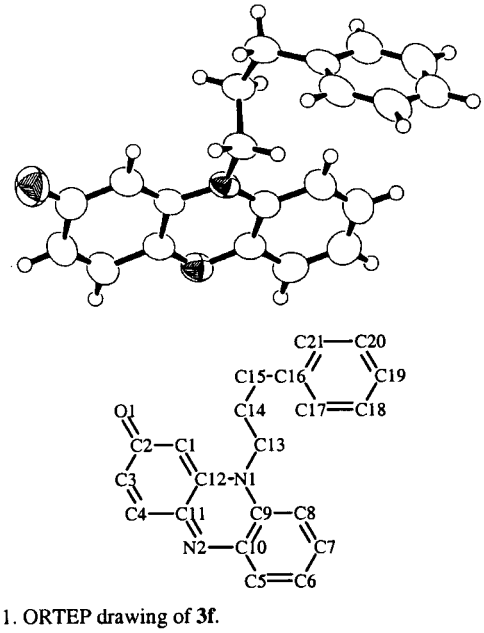


Figure 1. ORTEP drawing of **3f**.

Table 3

Crystallographic Analysis of Compound **3f**

Crystal Parameters	
Formula	$C_{21}H_{18}N_2O$
Crystal system	triclinic
Space group	$P\bar{1}$ (#2)
Lattice parameters	a = 9.616(2) Å
	b = 11.469(2) Å
	c = 8.482(2) Å
	α = 92.50(2)°
	β = 109.28(2) Å
	γ = 68.08(1)°
V	815.8(3) Å^3
Z	2
D_{calc} (g/cm^3)	1.280
μ (MoKα)	0.80
Refinement Parameters	
Number of reflections	1675 (I>3.0σ)
R [a]	0.042
Rw [b]	0.053
GOF	1.47

[a] R index = $\Sigma \| Fo \| - | Fc \| / \Sigma | Fo |$

[b] Rw index = $\{\Sigma w(| Fo | - | Fc |)^2 / \Sigma wFo^2\}^{1/2}$ where $w = [\sigma^2(Fo) + (p^2/4)(Fo)^2]^{-1}$

Table 4

Selected Bond Lengths (Å) and Bond Angles (°) for **3f**

O(1)-C(2)	1.240(3)	N(1)-C(9)	1.385(3)
N(1)-C(12)	1.377(3)	N(1)-C(13)	1.476(3)
N(2)-C(10)	1.368(3)	N(2)-C(11)	1.299(3)
C(1)-C(2)	1.429(3)	C(1)-C(12)	1.359(3)
C(3)-C(4)	1.322(3)	C(2)-C(3)	1.459(3)
C(4)-C(11)	1.444(3)	C(5)-C(10)	1.403(3)
C(5)-C(6)	1.366(3)	C(6)-C(7)	1.388(4)
C(11)-C(12)	1.463(3)	C(7)-C(8)	1.367(4)
C(14)-C(15)	1.528(3)	C(8)-C(9)	1.401(3)
C(16)-C(17)	1.380(3)	C(9)-C(10)	1.408(3)
C(17)-C(18)	1.383(4)	C(13)-C(14)	1.521(3)
C(18)-C(19)	1.360(4)	C(15)-C(16)	1.502(3)
C(19)-C(20)	1.378(4)	C(16)-C(21)	1.373(3)
C(20)-C(21)	1.376(4)		
C(9)-N(1)-C(12)	121.3(2)	C(5)-C(10)-C(9)	119.7(2)
C(9)-N(1)-C(13)	119.3(2)	N(2)-C(11)-C(4)	118.3(2)
C(12)-N(1)-C(13)	119.4(2)	N(2)-C(11)-C(12)	124.4(2)
C(10)-N(2)-C(11)	118.0(2)	C(4)-C(11)-C(12)	117.2(2)
C(2)-C(1)-C(12)	121.9(2)	N(1)-C(12)-C(1)	124.4(2)
O(1)-C(2)-C(1)	122.9(3)	N(1)-C(12)-C(11)	115.4(2)
O(1)-C(2)-C(3)	120.0(2)	C(1)-C(12)-C(11)	120.2(2)
C(1)-C(2)-C(3)	117.1(2)	N(1)-C(13)-C(14)	112.9(2)
C(2)-C(3)-C(4)	121.8(2)	C(13)-C(14)-C(15)	110.9(2)
C(3)-C(4)-C(11)	121.7(2)	C(14)-C(15)-C(16)	112.0(2)
C(6)-C(5)-C(10)	120.6(2)	C(15)-C(16)-C(17)	120.6(2)
C(5)-C(6)-C(7)	119.3(3)	C(15)-C(16)-C(21)	121.4(2)
C(6)-C(7)-C(8)	121.9(3)	C(17)-C(16)-C(21)	117.9(2)
C(7)-C(8)-C(9)	119.7(2)	C(16)-C(17)-C(18)	121.0(3)
N(1)-C(9)-C(8)	122.9(2)	C(17)-C(18)-C(19)	120.3(3)
N(1)-C(9)-C(10)	118.2(2)	C(18)-C(19)-C(20)	119.5(3)
C(8)-C(9)-C(10)	118.9(2)	C(19)-C(20)-C(21)	119.9(3)
N(2)-C(10)-C(5)	118.0(2)	C(16)-C(2l)-C(20)	121.3(3)
N(2)-C(10)-C(9)	122.3(2)		

Table 5

Atomic Coordinates (x10^4) and B_{eq}* for Compound **3f**

Atom	x	y	z	B_{eq} (Å^2)
O(1)	3717(2)	2394(2)	8(3)	7.03(6)
N(1)	9269(2)	-129(2)	1987(2)	3.79(4)
N(2)	9741(2)	2008(2)	1213(2)	4.21(5)
C(1)	6436(3)	1113(2)	1071(3)	4.62(6)
C(2)	5122(3)	2259(2)	303(3)	4.91(7)
C(3)	5492(3)	3296(2)	-146(3)	5.03(7)
C(4)	6976(3)	3190(2)	158(3)	4.86(6)
C(5)	12545(3)	893(2)	2295(3)	4.92(7)
C(6)	13852(3)	-171(3)	3040(3)	5.61(8)
C(7)	13642(3)	-1236(3)	3458(3)	5.66(7)
C(8)	12160(3)	-1256(2)	3131(3)	4.86(6)
C(9)	10805(3)	-175(2)	2363(3)	3.86(5)
C(10)	11005(3)	915(2)	1957(3)	3.97(6)
C(11)	8316(3)	2039(2)	941(3)	3.92(6)
C(12)	7966(3)	978(2)	1357(2)	3.69(5)
C(13)	9025(3)	-1295(2)	2234(3)	4.23(6)
C(14)	9058(3)	-1528(2)	4000(3)	4.52(6)
C(15)	9008(3)	-2820(2)	4256(3)	5.00(7)
C(16)	10420(3)	-3875(2)	4045(3)	4.40(6)
C(17)	10274(3)	-4480(2)	2592(3)	5.36(7)
C(18)	11587(4)	-5403(3)	2348(4)	6.58(8)
C(19)	13050(4)	-5735(3)	3550(4)	6.72(9)
C(20)	13211(4)	-5159(3)	5022(4)	6.69(8)
C(21)	11901(4)	-4238(2)	5255(3)	5.56(7)

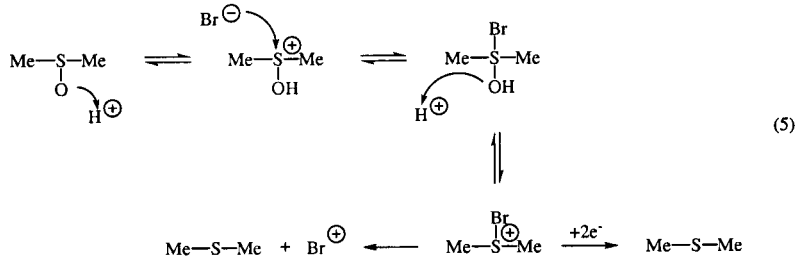
* Anisotropically refined atoms are given in the form of the isotropic equivalent thermal parameter defined as $(8/3)\pi^2[(aa^*)^2U_{11} + (bb^*)^2U_{22} + (cc^*)^2U_{33} + 2aa^*bb^*(\cos\gamma)U_{12} + 2aa^*cc^*(\cos\beta)U_{13} + 2bb^*cc^*(\cos\alpha)U_{23}]$.

for which the bond lengths of C=O, C=C, and C-C are reported to be 1.222, 1.322, and 1.477 Å, respectively [8].

The yields of these phenazinones, summarized in Table 2 with those of phenazine, demonstrate that 2(10*H*)-phenazinones bearing alkyl, aralkyl, and especially allyl (not brominated) groups at the 10 position can be obtained in moderate yields except for the anisyl derivatives and that methyl, allyl, and benzyl groups, especially the *p*-methoxybenzyl group are good leaving group for the present reaction and alkyl (except for methyl) and aralkyl groups do not leave efficiently. Our early investigation on the photoconductivities of 3*H*-phenothiazin-3-one and the related compounds suggested the favorable photophysical properties for the present 2(10*H*)-phenazinone derivatives [9]. The investigations on the photophysical properties of the phenazinones are anticipated.

Reaction Pathways.

The dealkylation was tried in nitroethane (a powerful electron acceptor), instead of dimethyl sulfoxide, for **1a**: In the presence of hydrobromic acid, **1a** in nitroethane was heated at 100-110° for 2 hours. Although some amount (25%) of **1a** was recovered by this reaction, the most part was changed to dark brown insoluble substance, and **3a** (2%) and **2** (in trace amount) were isolated, suggesting that the oxygen atom of the phenazi-



(5)

none moiety of **3** came from dimethyl sulfoxide (solvent). On the basis of these observations, a plausible mechanism of the formation of 10-alkyl-2(10*H*)-phenazinone is proposed as shown in Scheme 1. As the acid in dimethyl sulfoxide is essential for this reaction, dihydrophenazine may be oxidized by bromodimethylsulfonium bromide or the related reagent (hydroxydimethylsulfonium bromide and not dimethyl sulfoxide itself, equation 5) to give radical cation **6**, which changes to radical **7** by the attack of bromide anion at carbon atom of adjacent to ammonium-type nitrogen cation. Oxidation of this radical again leads to phenazinyl cation **8**, which changed to **2** and **3** by the reaction with dimethyl sulfoxide and bromide anion, respectively. On the other hand, the oxidant must change to dimethyl sulfide which was borne out by its characteristic odor (equation 5). Bromination of **4** with bromodimethylsulfonium cation gave **5** in the usual manner according to the aromatic electrophilic substitution mechanism.

EXPERIMENTAL

Melting points were determined with a Yanaco micromelting point apparatus (MP-500) and are uncorrected. The uv spectra were recorded on a Shimadzu UV-160A spectrophotometer. The

Scheme 1

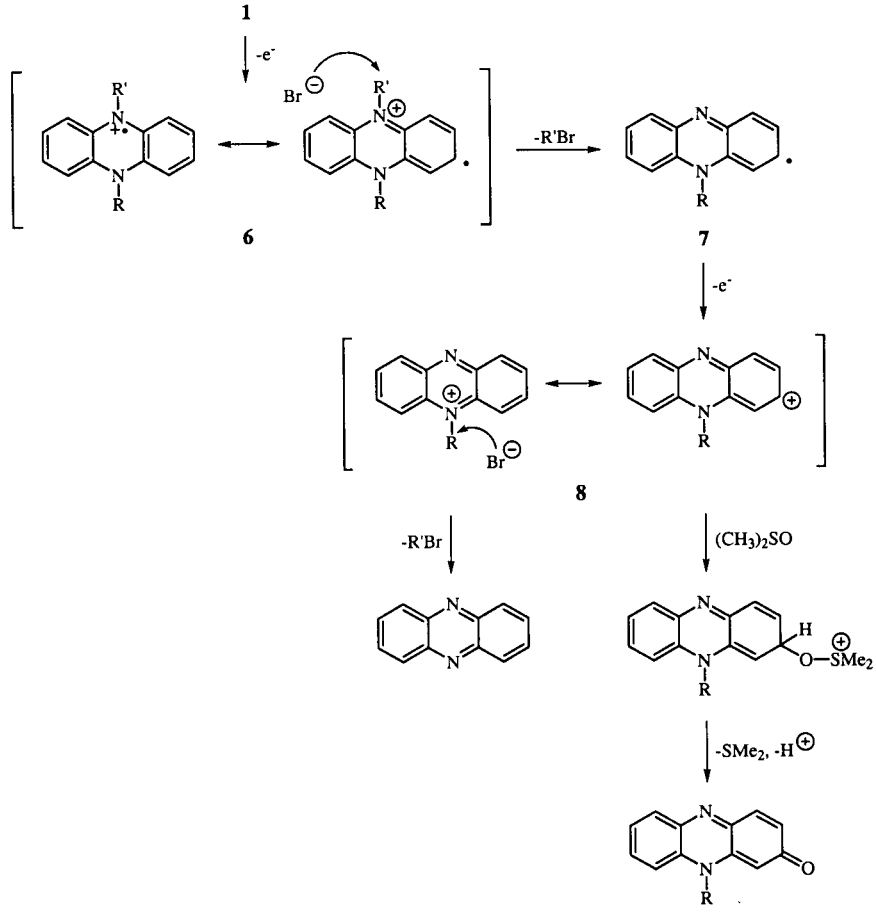


Table 6

Selected Bond Lengths (Å) and Bond Angles (°) for **5**

Br(1)-C(2)	1.88(1)	C(1)-C(11)	1.42(1)
Br(2)-C(7)	1.89(1)	C(2)-C(3)	1.39(2)
Cl(1)-C(1)	1.73(1)	C(3)-C(4)	1.35(2)
Cl(2)-C(6)	1.71(1)	C(4)-C(12)	1.41(1)
N(5)-C(12)	1.39(1)	C(6)-C(7)	1.38(1)
N(5)-C(13)	1.38(1)	C(6)-C(13)	1.41(1)
N(5)-C(16)	1.45(1)	C(7)-C(8)	1.38(1)
N(10)-C(11)	1.39(1)	C(8)-C(9)	1.37(1)
N(10)-C(14)	1.39(1)	C(9)-C(14)	1.39(1)
N(10)-C(15)	1.46(1)	C(11)-C(12)	1.39(1)
C(1)-C(2)	1.37(2)	C(13)-C(14)	1.39(1)
C(12)-N(5)-C(13)	117.1(8)	Br(2)-C(7)-C(6)	120.8(9)
C(12)-N(5)-C(16)	117.6(8)	Br(2)-C(7)-C(8)	116.9(8)
C(13)-N(5)-C(16)	123.6(8)	C(6)-C(7)-C(8)	122(1)
C(11)-N(10)-C(14)	116.7(8)	C(7)-C(8)-C(9)	118(1)
C(11)-N(10)-C(15)	122.5(9)	C(8)-C(9)-C(14)	122(1)
C(14)-N(10)-C(15)	119.9(9)	N(10)-C(11)-C(1)	124.0(9)
Cl(1)-C(1)-C(2)	119.7(9)	N(10)-C(11)-C(12)	117.5(9)
Cl(1)-C(1)-C(11)	119.4(8)	C(1)-C(11)-C(12)	118.5(9)
C(2)-C(1)-C(11)	121(1)	N(5)-C(12)-C(4)	123.0(9)
Br(1)-C(2)-C(1)	121(1)	N(5)-C(12)-C(11)	118.8(8)
Br(1)-C(2)-C(3)	118.5(9)	C(4)-C(12)-C(11)	118.1(9)
C(1)-C(2)-C(3)	120(1)	N(5)-C(13)-C(6)	123.5(9)
C(2)-C(3)-C(4)	119(1)	N(5)-C(13)-C(14)	118.0(9)
C(3)-C(4)-C(12)	123(1)	C(6)-C(13)-C(14)	118.5(9)
Cl(2)-C(6)-C(7)	121.0(8)	N(10)-C(14)-C(9)	121.1(9)
Cl(2)-C(6)-C(13)	119.6(8)	N(10)-C(14)-C(13)	119.0(8)
C(7)-C(6)-C(13)	119.4(9)	C(9)-C(14)-C(13)	120(1)

Table 7

Atomic Coordinates (x10^4) and B_{eq}* for Compound **5**

Atom	x	y	z	B_{eq}(Å^2)
Br(1)	9741(0.5)	2243(2)	1798(2)	7.15(8)
Br(2)	14241.9(0.5)	-226(2)	282(2)	6.37(7)
Cl(1)	10610(1)	-85(4)	3663(4)	6.7(2)
Cl(2)	13293(1)	1382(3)	-2290(4)	5.9(2)
N(5)	12040(4)	543(9)	-158(1)	3.9(4)
N(10)	11674(4)	-95(1)	140(1)	4.4(5)
C(1)	10797(4)	63(1)	155(1)	4.2(5)
C(2)	10446(5)	166(1)	73(2)	5.1(6)
C(3)	10616(5)	234(1)	-89(2)	5.9(7)
C(4)	11128(5)	195(1)	-163(2)	5.4(6)
C(6)	13053(4)	21(1)	-63(1)	3.8(5)
C(7)	13435(4)	-48(1)	54(2)	4.1(5)
C(8)	13253(5)	-133(1)	199(2)	4.7(6)
C(9)	12668(5)	-148(1)	226(1)	4.4(6)
C(11)	11321(4)	17(1)	72(1)	3.6(5)
C(12)	11503(4)	90(1)	-84(1)	3.5(5)
C(13)	12453(4)	-1(1)	-40(1)	3.3(5)
C(14)	12265(4)	-80(1)	110(1)	3.5(5)
C(15)	11442(6)	-234(1)	209(2)	6.0(7)
C(16)	12080(5)	44(1)	-355(1)	5.5(6)

*Anisotropically refined atoms are given in the form of the isotropic equivalent thermal parameter defined as $(8/3)\pi^2[(aa^*)^2U_{11} + (bb^*)^2U_{22} + (cc^*)^2U_{33} + 2aa^*bb^*(\cos\gamma)U_{12} + 2aa^*cc^*(\cos\beta)U_{13} + 2bb^*cc^*(\cos\alpha)U_{23}]$.

ir spectra were obtained on a Jasco FT/IR-230 spectrophotometer and nmr spectra were recorded on a JNM-GX270 (270 MHz) spectrometer using tetramethylsilane as internal standard. X-Ray diffraction data were collected by using Rigaku AFC5R diffractometer with graphite monochromated Mo-Kα radiation (λ = 0.71069 Å) and an 18 kW rotating anode generator. Cell dimensions were obtained by least-square fitting from 20 high angle reflections. All computations for the structure determination were carried out on VAX station 3 100 or INDY R5000 using a crystallographic program packageTEXSAN or teXan [10].

Materials.

General procedure: A typical example of the preparation procedures in detail is described on the synthesis of 10-(3-phenylpropyl)-2(10*H*)-phenazinone (**3f**). The following 10-substituted 2(10*H*)-phenazinones **3a, c-e, g-i, m** were prepared similarly.

10-(3-Phenylpropyl)-2(10*H*)-phenazinone (**3f**).

A mixture of 5-methyl-10-(3-phenylpropyl)-5,10-dihydrophenazine (**1f**) (0.31 g, 0.97 mmole) and hydrobromic acid (0.66 g of 47%, 3.9 mmoles) in dimethyl sulfoxide (5 ml) was heated at 100-110° for 2 hours. After being cooled to rt, the reaction mixture was poured into a large amount of water, neutralized with aqueous sodium hydroxide solution and extracted with toluene. The organic layer was dried over anhydrous sodium sulfate and evaporated under reduced pressure. The residue was purified by column chromatography on silica gel with ethyl acetate to give **3f** (0.2 g), recrystallized from ethyl acetate, mp 159-160°; uv (methanol): λ_{max} nm (log ε) 232 (4.46), 287 (4.57), 363 (3.94), and 518 (4.06); ir (potassium bromide): ν 1626 (CO) cm^{-1}; ^{1}H nmr (deuteriochloroform): δ 2.18-2.29 (2H, m), 2.87-2.93 (2H, t), 4.24-4.30 (2H, t), 6.44 (1H, s), 7.13-7.21 (1H, m), 7.29-7.39 (6H, m), 7.43-7.49 (1H, m), 7.60-7.69 (2H, m), and 8.01-8.04 (1H, m); ^{13}C nmr (deuteriochloroform): δ 26.8, 32.7, 45.8, 98.9, 113.2, 124.4, 126.5, 128.2, 128.6, 130.7, 131.5, 132.9, 134.4, 135.2, 135.8, 136.9, 139.5, 147.2, and 183.2 ppm; ms: m/z 314 (M$^+$).

Anal. Calcd. for $C_{21}H_{18}N_2O$: C, 80.23; H, 5.77; N, 8.91. Found: C, 80.33; H, 5.73; N, 8.64.

10-Methyl-2(10*H*)-phenazinone (**3a**) [11].

A mixture of 5,10-dimethyl-5,10-dihydrophenazine (0.15 g, 0.73 mmole) and hydrobromic acid (0.50 g of 47%, 2.9 mmoles) in dimethyl sulfoxide (5 ml) was heated at 100-110° for 2 hours. After the usual work-up, the solid obtained was purified by chromatography with ethyl acetate gave 10-methyl-2(10*H*)-phenazinone **3a** (20 mg), which was recrystallized from benzene; mp 202-204° (lit 200°); uv (methanol): λ_{max} nm (log ε) 231 (4.40), 286 (4.52), 362 (3.89), and 516 (4.00); ir (potassium bromide): ν 1631 (CO) cm^{-1}; ^{1}H nmr (deuteriochloroform): δ 3.80 (3H, s), 6.26 (1H, s), 7.11-7.12 (1H, m), 7.43-7.71 (4H, m), and 8.00-8.04 (1H, m). Phenazine was isolated from the first eluent of the chromatography in 77% yield.

10-Butyl-2(10*H*)-phenazinone (**3c**) [5].

Reaction of 5-butyl-10-methyl-5,10-dihydrophenazine (0.12 g, 0.46 mmole) with hydrobromic acid (0.32 g of 47%, 1.8 mmoles) in dimethyl sulfoxide (5 ml) gave 10-butyl-2(10*H*)-phenazinone **3c** (80 mg), mp 183-184.5° (lit 195-197°); uv (methanol): λ_{max} nm (log ε) 232 (4.48), 287 (4.59), 362 (3.96), and 518 (4.08); ir (potassium bromide): ν 1624 (CO) cm^{-1}; ^{1}H nmr (deuteriochloroform): δ 1.05-1.11 (3H, t), 1.55-1.69 (2H, m), 1.86-1.98 (2H, m), 4.35-4.41 (2H, t), 6.68 (1H, s), 7.20-7.23 (1H, m), 7.52-7.64 (2H, m), 7.73-7.83 (2H, m), and 8.10-8.13 (1H, d).

Anal. Calcd. for $C_{16}H_{16}N_2O$: C, 76.16; H, 6.39; N, 11.10. Found: C, 76.06; H, 6.43; N, 11.01.

10-Dodecyl-2(10*H*)-phenazinone (**3d**).

Reaction of 5-dodecyl-10-methyl-5,10-dihydrophenazine (0.12 g, 0.34 mmole) with hydrobromic acid (0.23 g of 47%, 1.3 mmoles) in dimethyl sulfoxide (5 ml) gave 10-dodecyl-2(10*H*)-phenazinone **3d** (60 mg), mp 115-117°; uv (hexane): λ_{max} nm (log ε) 229 (4.34), 280 (4.53), 290 (4.51), 338 (3.83), 355 (3.77), and 508 (3.97); ir (potassium bromide): 1625 (CO) cm^{-1}; ^1H nmr (deuteriochloroform): δ 0.85-0.90 (3H, m), 1.27-1.50 (18H, m), 1.81-1.87 (2H, m), 4.16-4.22 (2H, m), 6.20 (1H, s), 7.04-7.09 (1H, m), 7.41-7.73 (4H, m), and 7.98-8.01 (1H, d).

Anal. Calcd. for $C_{24}H_{32}N_2O$: C, 79.08; H, 8.85; N, 7.68. Found: C, 79.38; H, 9.11; N, 7.66.

10-Octadecyl-2(10*H*)-phenazinone (**3e**).

Reaction of 5-methyl-10-octadecyl-5,10-dihydrophenazine (0.11 g, 0.23 mmole) with hydrobromic acid (0.11 g of 47%, 0.6 mmole) in dimethyl sulfoxide (5 ml) gave 10-octadecyl-2(10*H*)-phenazinone **3e** (70 mg), mp 102°; uv (hexane): λ_{max} nm (log ε) 230 (4.33), 281 (4.50), 289 (4.48), 340 (3.84), 355 (3.75), and 507 (3.94); ir (potassium bromide): ν 1629 (CO) cm^{-1}; ^1H nmr (deuteriochloroform): δ 0.85-0.90 (3H, m), 1.16-2.06 (32H, m), 4.24-4.30 (2H, m), 6.41 (1H, s), 7.14-7.17 (1H, d), 7.46-7.77 (4H, m), and 8.04-8.07 (1H, d).

Anal. Calcd for $C_{30}H_{44}N_2O$: C, 80.31; H, 9.88; N, 6.24. Found: C, 80.34; H, 10.13; N, 6.16.

10-Phenethyl-2(10*H*)-phenazinone (**3g**).

Reaction of 5-(2-phenethyl)-10-methyl-5,10-dihydrophenazine (0.09 g, 0.31 mmole) with hydrobromic acid (0.21 g of 47%, 1.2 mmoles) in dimethyl sulfoxide (4 ml) gave 70 mg of 10-phenethyl-2(10*H*)-phenazinone **3g**, mp 224-225°; uv (methanol): λ_{max} nm (log ε) 232 (4.46), 287 (4.57), 364 (3.96), and 517 (4.07); ir (potassium bromide): ν 1625 (CO) cm^{-1}; ^1H nmr (deuteriochloroform): δ 3.16-3.22 (2H, t), 4.49-4.55 (2H, t), 6.60 (1H, s), 7.16-7.20 (1H, m), 7.24-7.40 (5H, m), 7.47-7.55 (2H, m), 7.68-7.75 (2H, m), and 8.05-8.09 (1H, d).

Anal. Calcd. for $C_{20}H_{16}N_2O$: C, 79.98; H, 5.37; N, 9.33. Found: C, 80.19; H, 5.23; N, 9.41.

10-Benzyl-2(10*H*)-phenazinone (**3h**).

Reaction of 5-benzyl-10-methyl-5,10-dihydrophenazine (0.30 g, 1.1 mmoles) with hydrobromic acid (0.72 g of 47%, 4.2 mmoles) in dimethyl sulfoxide (5 ml) gave 70 mg of 10-benzyl-2(10*H*)-phenazinone **3h**, mp 262-264°; uv (methanol): λ_{max} nm (log ε) 231 (4.26), 287 (4.35), 363 (3.78), and 514 (3.87); ir (potassium bromide): ν 1628 (CO) cm^{-1}; ^1H nmr (deuteriochloroform): δ 5.50 (2H, s), 6.24 (1H, s), 7.07-7.18 (3H, m), 7.27-7.38 (3H, m), 7.44-7.50 (2H, m), 7.61-7.69 (2H, m), and 8.05-8.08 (1H, d).

Anal. Calcd. for $C_{19}H_{14}N_2O$: C, 79.70; H, 4.93; N, 9.78. Found: C, 79.33; H, 4.88; N, 9.84.

10-(4-Nitrobenzyl)-2(10*H*)-phenazinone (**3i**).

Reaction of 5-methyl-10-(4-nitrobezyl)-5,10-dihydrophenazine (0.05 g, 0.15 mmole) with hydrobromic acid (0.10 g of 47%, 0.6 mmole) in dimethyl sulfoxide (4 ml) gave 10 mg of 10-(4-nitrobenzyl)-2(10*H*)-phenazinone **3i**, mp 270-272°; uv (methanol): λ_{max} nm (log ε) 230 (4.52), 278 (4.62), 361 (4.00), and 514 (4.10); ir (potassium bromide): ν 1631 (CO) cm^{-1}; ^1H nmr (deuteriochloroform): δ 5.62 (2H, s), 6.28 (1H, s), 7.11-7.16 (1H, m), 7.28-7.41 (3H, m), 7.51-7.57 (1H, m), 7.64-7.76 (2H, m), 8.11-8.15 (1H, m), and 8.20-8.25 (2H, d).

Anal. Calcd. for $C_{19}H_{13}N_3O_3$: C, 68.88; H, 3.95; N, 12.68. Found: C, 68.83; H, 3.72; N, 12.78.

10-Allyl-2(10*H*)-phenazinone (**3m**).

Reaction of 5,10-diallyl-5,10-dihydrophenazine (0.16 g, 0.61 mmole) with hydrobromic acid (0.42 g of 47%, 2.4 mmoles) in dimethyl sulfoxide (5 ml) gave 10-allyl-2(10*H*)-phenazinone **3m** (60 mg) mp 178-180°; uv (methanol): λ_{max} nm (log ε) 231 (4.40), 287 (4.51), 363 (3.90), and 516 (4.01); ir (potassium bromide): ν 1625 (CO) cm^{-1}; ^1H nmr (deuteriochloroform): δ 4.88-4.91 (2H, m), 5.13-5.21 (1H, m), 5.37-5.42 (1H, m), 5.95-6.08 (1H, m), 6.30 (1H, s), 7.09-7.13 (1H, m), 7.45-7.51 (2H, m), 7.64-7.73 (2H, m), and 8.02-8.06 (1H, m).

Anal. Calcd. for $C_{15}H_{12}N_2O$: C, 76.25; H, 5.12; N, 11.86. Found: C, 76.55; H, 4.91; N, 11.90.

Preparation of 5,10-Disubstituted Dihydrophenazines **1**. Dihydrophenazine Derivatives **1a** [7], **1b** [12], **1h** [7], and **1i** [7] are already reported. Others were prepared as follows:

5-Methyl-5,10-dihydrophenazine **1b** [12].

A solution of commercially available phenazine (4.05 g, 22.5 mmoles) and dimethyl sulfate (20 ml, 210 mmoles) in nitrobenzene (35 ml) was heated at 100° for 7 minutes and then cooled in an ice-bath. The solid deposited was filtered and washed with a small amount of diethyl ether to give 5-methylphenazinium methyl sulfate (5.16 g, 75%), mp 155-157° (lit [13] 150-153°). To a hot solution of this salt (3.0 g, 9.71 mmoles) in ethanol (75 ml) was added sodium dithionite (17 g) and then to this mixture was added water (800 ml) by small portions under vigorous shaking. A solid **1b** deposited was collected by filtration and dried under reduced pressure (1.83 g, 94%), recrystallized from hexane under argon atmosphere, mp 168-172° in capillary sealed under vacuum (lit [12] mp 164°).

5-Methyl-10-(3-phenylpropyl)-5,10-dihydrophenazine (**1f**).

To a stirred solution of **1b** (0.53 g, 2.7 mmoles) in 1,2-dimethoxyethane (10 ml) was added dropwise a solution of *n*-butyllithium in hexane (1.7 ml of 15% solution, 2.7 mmoles) under argon atmosphere. To this reaction mixture was added dropwise a solution of 1-bromo-3-phenylpropane (0.54 g, 2.7 mmoles) in 1,2-dimethoxyethane (2 ml) at rt and then the mixture was stirred for overnight. After usual work-up, the solid obtained was purified by chromatography on silica gel with toluene-hexane (1:1, v/v) as the eluent to give 5-methyl-10-(3-phenylpropyl)-5,10-dihydrophenazine (**1f**) in 57% yield (0.49 g), mp 115.5-117°; uv (hexane): λ_{max} nm (log ε) 250 (4.78) and 344 (3.98); ^1H nmr (benzene-d_6): δ 1.79 (2H, quin), 2.35 (3H, s), 2.42-2.49 (2H, m), 3.18-3.22 (2H, m), 6.18-6.67 (8H, m), and 7.03-7.13 (5H, m).

Anal. Calcd. for $C_{22}H_{22}N_2$: C, 84.04; H, 7.05; N, 8.91. Found: C, 84.26; H, 7.06; N, 9.01.

5-Butyl-10-methyl-5,10-dihydrophenazine (**1c**).

After addition of a solution of *n*-butyllithium in hexane (3.9 ml of 15% solution, 6.9 mmoles) to a stirred solution of **1b** (1.21 g, 6.2 mmoles) in 1,2-dimethoxyethane (20 ml), a solution of 1-bromobutane (0.66 ml, 6.2 mmoles) in 1,2-dimethoxyethane (5 ml) was added to this reaction mixture at rt. After the

usual work-up, the solid obtained was purified by chromatography on silica gel eluting with toluene to give 5-butyl-10-methyl-5,10-dihydrophenazine in 11% yield, mp 85-88°; uv (hexane): λ_{max} nm (log ε) 249 (4.77) and 349 (3.96); ^{1}H nmr (benzene-d_6): δ 0.73 (3H, t), 1.05-1.13 (2H, m), 1.39-1.48 (2H, m), 2.44 (3H, s), 3.16-3.22 (2H, t), 6.09-6.12 (2H, m), 6.27-6.30 (2H, m), and 6.66-6.73 (4H, m).

Anal. Calcd. for $C_{17}H_{20}N_2$: C, 80.91; H, 7.99; N, 11.10. Found: C, 80.97; H, 8.25; N, 11.31.

5-Dodecyl-10-methyl-5,10-dihydrophenazine (**1d**).

By the similar reaction procedure to that of **1c**, 5-dodecyl-10-methyl-5,10-dihydrophenazine was obtained in 50% yield, mp 68-69°; uv (hexane): λ_{max} nm (log ε) 250 (4.68) and 347 (3.88); ^{1}H nmr (benzene-d_6): δ 0.90-1.30 (23H, m), 2.46 (3H, s), 3.23-3.29 (2H, t), 6.09-6.13 (2H, m), 6.32-6.35 (2H, m), and 6.66-6.75 (4H, m).

Anal. Calcd. for $C_{25}H_{36}N_2$: C, 82.36; H, 9.95; N, 7.68. Found: C, 82.22; H, 9.94; N, 7.67.

5-Methyl-10-Octadecyl-5,10-dihydrophenazine (**1e**).

By the similar reaction procedure to that of **1c**, 5-methyl-10-octadecyl-5,10-dihydrophenazine, was obtained in 40% yield, mp 79-80°; uv (hexane): λ_{max} nm (log ε) 250 (4.79) and 345 (3.97); ^{1}H nmr (benzene-d_6): δ 0.90 (3H, t), 1.16-1.35 (30H, m), 1.52-1.57 (2H, m), 2.45 (3H, s), 3.22-3.28 (2H, t), 6.10-6.13 (2H, m), 6.32-6.35 (2H, m), and 6.66-6.75 (4H, m).

Anal. Calcd. for $C_{31}H_{48}N_2$: C, 82.98; H, 10.78; N, 6.24. Found: C, 82.72; H, 11.13; N, 6.28.

5-(2-Phenethyl)-10-methyl-5,10-dihydrophenazine (**1g**).

By the similar reaction procedure to that of **1c**, 5-(2-phenethyl)-10-methyl-5,10-dihydrophenazine was obtained in 4% yield, mp 131.5-134°; uv (hexane): λ_{max} nm (log ε) 249 (4.79) and 347 (3.98); ^{1}H nmr (benzene-d_6): δ 2.45 (3H, s), 2.77 (2H, t), 3.50 (2H, t), 6.09-6.74 (8H, m), and 6.95-7.16 (5H, m).

Anal. Calcd. for $C_{21}H_{20}N_2$: C, 83.96; H, 6.71; N, 9.33. Found: C, 84.04; H, 6.57; N, 9.26.

5-(4-Methoxybenzyl)-10-methyl-5,10-dihydrophenazine (**1j**).

By a similar reaction procedure to that of **1c**, 5-(4-methoxybenzyl)-10-methyl-5,10-dihydrophenazine was obtained in 2% yield, mp 153-155°; uv (hexane): λ_{max} nm (log ε) 249 (4.77) and 346 (3.91); ^{1}H nmr (benzene-d_6): δ 2.55 (3H, s), 3.28 (3H, s), 4.48 (2H, s), 6.17-6.28 (4H, m), and 6.54-7.04 (8H, m).

Anal. Calcd. for $C_{21}H_{20}N_2O$: C, 79.72; H, 6.37; N, 8.85. Found: C, 79.60; H, 6.35; N, 8.70.

5,10-Dibenzyl-5,10-dihydrophenazine (**1k**).

To a stirred solution of 5,10-dihydrophenazine (3.03 g, 16.7 mmoles) in 1,2-dimethoxyethane (50 ml) was added dropwise a solution of *n*-butyllithium in hexane (20.6 ml of 15% solution, 33 mmoles) under argon atmosphere. To this reaction mixture was added dropwise benzyl bromide (4.0 ml, 33 mmoles) at rt and then the mixture was stirred for overnight. After usual work-up, the solid obtained was purified by chromatography on silica gel with toluene as the eluent to give 5,10-dibenzyl-5,10-dihydrophenazine in 15% yield, mp 214-215°; uv (hexane): λ_{max} nm (log ε) 250 (4.68) and 351 (3.80); ^{1}H nmr (benzene-d_6): δ 4.42 (4H, s), 6.08-6.11 (4H, m), 6.37-6.41 (4H, m), and 7.01-7.123 (10H, m).

Anal. Calcd. for $C_{26}H_{22}N_2$: C, 86.15; H, 6.12; N, 7.73. Found: C, 86.57; H, 6.04; N, 7.77.

5,10-Diallyl-5,10-dihydrophenazine (**1m**).

A similar method to that used for **1k** gave 5,10-diallyl-5,10-dihydrophenazine in 34% yield, mp 117-118°; λ_{max} nm (log ε) 250 (4.83) and 349 (3.99); ^{1}H nmr (benzene-d_6): δ 3.65-3.68 (4H, m), 4.93-5.14 (4H, m), 5.38-5.51 (2H, m), 6.05-6.23 (4H, m), and 6.56-6.63 (4H, m).

Anal. Calcd. for $C_{18}H_{18}N_2$: C, 82.41; H, 6.92; N, 10.68. Found: C, 82.28; H, 6.95; N, 10.56.

5,10-Bis(4-methoxybenzyl)-5,10-dihydrophenazine (**1n**).

By a similar reaction procedure to that for **1k**, 5,10-bis(4-methoxybenzyl)-5,10-dihydrophenazine was obtained in 24% yield, mp 231-233° dec; uv (hexane): λ_{max} nm (log ε) 249 (4.06) and 349 (3.17); ^{1}H nmr (benzene-d_6): δ 3.26 (6H, s), 4.44 (4.H, s), 6.18-6.21 (4H, m), 6.45-6.50 (4H, m), 6.71-6.74 (4H, m), and 7.08-7.11 (4H, m).

Anal. Calcd. for $C_{28}H_{26}N_2O_2$: C, 79.59; H, 6.20; N, 6.63. Found: C, 79.69; H, 6.17; N, 6.63.

1,6-Dichloro-5,10-dimethyl-5,10-dihydrophenazine (**4**).

A similar method to that for **1k** gave 1,6-dichloro-5,10-dimethyl-5,10-dihydrophenazine in 31% yield, mp 123-124°; ^{1}H nmr (benzene-d_6): δ 3.07 (6H, s), 6.19 (1 H, d), 6.22 (1H, d), 6.45 (2H, t), 6.78 (1H, d), and 6.81 (1H, d).

Anal. Calcd. for $C_{14}H_{12}N_2Cl_2$: C, 60.2; H, 4.3; N, 10.0. Found: C, 60.3; H, 4.1; N, 10.0.

2,7-Dibromo-1,6-dichloro-5,10-dimethyl-5,10-dihydrophenazine (**5**).

To a hot solution of **4** (0.15 g, 0.53 mmole) in dimethyl sulfoxide (2 ml) was added hydrobromic acid (0.3 ml of 47% aqueous solution) and the mixture was heated at 80-90° for 2 hours. After cooling, the reaction mixture was treated with an aqueous solution of ammonium hydroxide (0.5 ml) and extracted with dichloromethane. The residual solid by the evaporation of the solvent of the extract was purified by chromatography with toluene-hexane (1:1, v/v) to give yellow prisms (from hexane-benzene) in 61% yield (0.11 g), mp 165-166°; ^{1}H nmr (benzene-d_6): δ 2.78 (6H, s), 5.81 (1H, s), 5.84 (1H, s), 6.84 (1H, d), and 6.87 (1H, d).

Anal. Calcd. for $C_{14}H_{10}Br_2Cl_2N_2$: C, 38.48; H, 2.31; N, 6.41. Found: C, 38.26; H, 2.15; N, 6.36.

Crystal data for **5**: $C_{14}H_{10}Br_2Cl_2N_2$. Monochnic, a= 23.076(5), b = 9.051 (1), c = 7.318(3) Å, β = 90.30(3)°, V = 1528.5(7) Å^3, space group $P2_1/n$ (#14), Dc = 1.899 gcm^{-3}, Z = 4, μ (Mo-Kα) = 55.95 cm^{-1}. Final refinements converged to R (Rw) = 0.045 (0.071), S = 1.89. The crystallographic data are shown in Tables 6-7.

2-Bromophenazine.

By a similar reaction procedure to that of **3a** with hydrobromic acid, 2-bromophenazine was obtained in 7% yield in the first eluent *via* chromatography with dichloromethane, mp 143-144.5° (lit [14] 149-150°); ms: m/z = 258 (M$^+$); ^{1}H nmr (deuteriochloroform): δ 7.86-7.92 (3H, m), 8.12-8.27 (3H, m), and 8.48 (1H, s).

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