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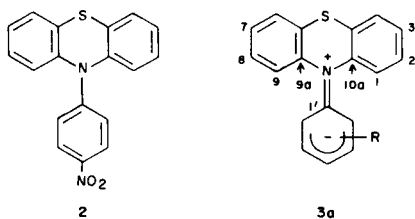
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The crystal structure of title compound, **4**, shows that the 10-aryl group is parallel to the plane bisecting the pyridobenzothiazine ring. This structure is in contrast to that normally found for phenothiazines substituted with electron-withdrawing substituents on the 10-phenyl ring. In those compounds, the 10-aryl group is perpendicular to the plane bisecting the phenothiazine ring. The esr spectrum of the cation radical of **4** shows that the radical is located on the hetero ring system which is opposite to that of the cation radical of 4'-dimethylamino-10-phenylphenothiazine in which the radical is located on the 10-aryl ring.

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As a rule, most 10-arylphenothiazines have a high twist angle between the planes of the aryl ring and the phenothiazine ring ( $> 70^\circ$ ) [1]. However, in a few instances, we have observed that strong electron-withdrawing groups can alter this geometry. Substituents such as 10-(2'-pyrazyl), **1**, [2] and 10-(4'-nitrophenyl), **2**, [3] exert the electronic pull on the electron-rich phenothiazine moiety. As a result, the resonance contributing structures where N(10)  $sp^2$  lone-pair of electrons mesomerically offset the electron drain of the 10-substituent become increasingly important, **3a**. This is quite apparent from the crystal structures



of **1** and **2** where indeed the plane of the 10-aryl substituent bisects the plane defined by S(5), N(10), and C(1') atoms [2,3]. In order to accommodate the maximum overlap of N(10)-C(1')  $sp^2$ - $\pi$  orbitals and minimize steric interactions with *peri* hydrogens, H(1) and H(9), the phenothiazine itself is more puckered and the 10-substituent pushed further up to the convex side of the "butterfly angle" of phenothiazine.

Similar results are inferred from studies in solution. We have interpreted the large downfield shifts of C(1), C(3), and C(4a) (up to 15 ppm) in the  $^{13}\text{C}$  spectra of **1** and **2** as a strong indication of similar electronic interactions in solution [4].

The most intriguing observation which prompted us to examine the crystal structure of the title compound, **4**, stems from the studies of cation radicals. When compound

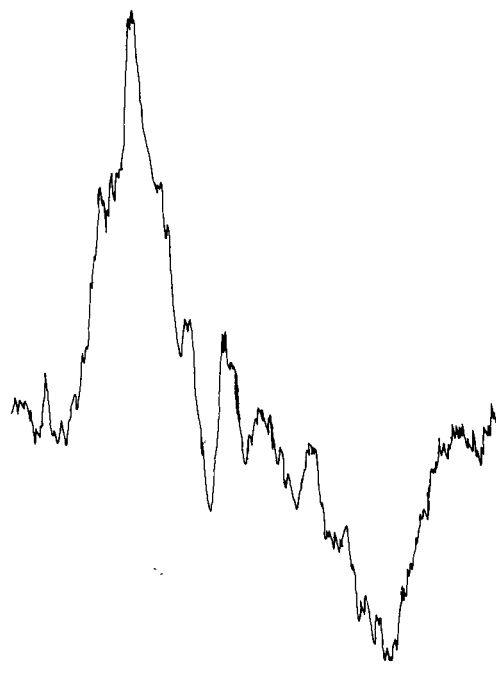


Figure 1

The observed esr spectrum of the 10-phenylpyrido[3,2-*b*]benzothiazinium cation radical as  $1 \times 10^{-3}M$  solution in 80% aqueous sulfuric acid.

**4** was oxidized to its cation radical, **4a**, it gave rise to an esr signal superimposable with that of other 10-arylpyrido-benzothiazines (Figures 1 and 2). The quality of the esr spectra are rather poor; they are used simply as showing qualitative similarities of the two cation radicals. By contrast, the 4'-dimethylamino-10-phenylphenothiazine, **5**, was reported to yield anilinium type radical **5a** markedly different from all other 10-arylphenothiazinium cation

Table 1

Fractional atomic coordinates ( $\times 10^4$ ) for non-hydrogen and ( $\times 10^3$ ) for hydrogen atoms, with "equivalent" thermal parameters for non-hydrogen ( $\times 10^4$ ) and isotropic for hydrogen atoms ( $\times 10^3$ ). The estimated standard deviations are given in parenthesis.

Atom	X	Y	Z	$U_{eq}/U$
N(1)	2123(3)	5718(3)	4092(1)	506(6)
C(2)	599(4)	5450(4)	4180(2)	546(8)
C(3)	-279(4)	4335(4)	3869(2)	599(8)
C(4)	415(4)	3381(4)	3479(2)	579(8)
C(4a)	1989(4)	3567(3)	3405(1)	466(7)
S(5)	2958(1)	2203(1)	3011(0)	604(2)
C(5a)	4391(4)	3327(3)	2726(1)	482(7)
C(6)	4990(5)	2894(5)	2174(2)	665(9)
C(7)	6197(5)	3650(5)	1960(2)	725(10)
C(8)	6797(4)	4875(5)	2305(2)	646(9)
C(9)	6188(3)	5365(4)	2839(1)	485(7)
C(9a)	4984(3)	4618(3)	3057(1)	439(6)
N(10)	4356(3)	5120(3)	3609(1)	435(5)
C(10a)	2798(3)	4804(3)	3703(1)	388(6)
C(1')	5096(3)	6423(3)	3939(1)	411(6)
C(2')	4757(4)	7835(3)	3699(1)	495(7)
C(3')	5494(4)	9063(3)	4001(1)	468(7)
C(4')	6614(3)	8920(3)	4560(1)	430(6)
C(5')	6932(4)	7478(3)	4799(1)	463(7)
C(6')	6181(3)	6247(3)	4490(1)	427(6)
N(4')	7335(3)	10152(3)	4859(1)	617(7)
C(7')	8347(5)	10020(5)	5478(2)	674(10)
C(8')	6978(6)	11614(4)	4602(2)	752(12)
H(2)	9(4)	613(4)	448(2)	73(10)
H(3)	-124(4)	417(4)	399(2)	62(9)
H(4)	-21(4)	252(4)	326(2)	59(9)
H(6)	459(4)	206(4)	197(2)	82(12)
H(7)	669(4)	334(4)	158(2)	66(10)
H(8)	754(4)	545(4)	219(2)	55(9)
H(9)	647(4)	625(2)	303(2)	71(11)
H(2')	399(4)	795(4)	330(2)	61(9)
H(3')	530(3)	1000(3)	382(1)	37(7)
H(5')	771(4)	726(3)	518(1)	51(8)
H(6')	643(3)	521(3)	465(1)	47(7)
H(7')1	861(5)	1089(6)	564(2)	110(16)
H(7')2	927(7)	921(7)	544(3)	163(23)
H(7')3	779(6)	961(5)	579(2)	108(16)
H(8')1	729(6)	1233(5)	492(2)	116(16)
H(8')2	575(8)	1199(7)	453(3)	190(28)
H(8')3	716(4)	1176(4)	417(2)	72(11)

Table 2

## Torsion Angles and Ring Puckering Parameters

Torsion angles around the central phenothiazine ring:

C(5a)-S(5)-C(4a)-C(10a)	-32.3(4)°
S(5)-C(4a)-C(10a)-N(10)	10.2(4)
C(4a)-C(10a)-N(10)-C(9a)	24.4(4)
C(10a)-N(10)-C(9a)-C(5a)	-16.8(4)
N(10)-C(9a)-C(5a)-S(5)	-4.8(4)
C(9a)-C(5a)-S(5)-C(4a)	29.6(3)

Torsion angles about the N(10)-C(1') bond:

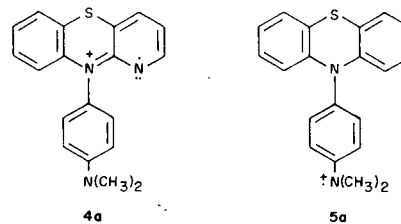
C(9a)-N(10)-C(1')-C(2')	78.8(3)°
C(9a)-N(10)-C(1')-C(6')	-99.5(3)
C(10a)-N(10)-C(1')-C(2')	-78.7(3)
C(10a)-N(10)-C(1')-C(6')	103.0(3)

Torsion angles about the C(4')-N(4') bond:

C(3')-C(4')-N(4')-C(7')	172.5(3)°
C(3')-C(4')-N(4')-C(8')	-0.9(4)
C(5')-C(4')-N(4')-C(7')	-6.4(4)
C(5')-C(4')-N(4')-C(8')	-179.8(3)

Puckering parameters:

Central	Ideal boat conformation
$Q = 0.432 \text{ \AA}$	$q_2 = Q$
$q_2 = 0.421$	$q_3 = 0$
$q_3 = 0.095$	
$\theta = 102.7^\circ$	$\theta = 90^\circ$
$\phi_2 = 3.9^\circ$	$\phi_2 = 0^\circ$



## EXPERIMENTAL

radicals studied [5]. The intense blue solution of **5a** with the  $g$  value of 2.0030 and spectral width of 7 mT was analogous to the Wurster's Blue cation radical [6] (as opposed to orange-brown 10-arylphenothiazinium cation radicals with average  $g$  value of 2.0050 and spectral width of 2.5 mT). These authors interpreted this in terms of a greater overlap of the 10-aryl  $\pi$ -system with the  $p$ -orbital of N(10) with the radical no longer being phenothiazine-centered and where the spin distribution is partially localized on the dialkylamino group.

That the radical cation of **4** is delocalized mainly in the phenothiazine ring is probably due to the 1-aza group resonance contribution to the stabilization of the radical as indicated in structure **4a**.

The crystals of **4** are pale grey prisms. A crystal of  $0.20 \times 0.18 \times 0.08$  mm in dimensions was selected for the determination of unit cell parameters and the intensity measurements. The unit cell parameters were obtained from a least-squares analysis of 15 reflections with  $2\theta$  value from 11 to  $28^\circ$  measured on a Syntex P2<sub>1</sub> automatic diffractometer with graphite monochromatized  $\text{CuK}\alpha$  radiation. The crystal is monoclinic and the space group,  $\text{P2}_1/n$ , was deduced from systematic absences ( $h0l$  absent with  $h+l$  odd and  $0k0$  absent with  $k$  odd). The unit cell parameters are  $a = 8.580(1)$ ,  $b = 8.984(2)$ ,  $c = 20.880(3) \text{ \AA}$ ,  $\beta = 98.42(1)^\circ$ , with the unit cell volume  $V = 1592.1(4) \text{ \AA}^3$ . The formula weight of **4**,  $\text{C}_{19}\text{H}_{17}\text{N}_3\text{S}$ , is 319.4 and there are four molecules in a unit cell; therefore, the calculated density of the crystal is  $1.333 \text{ g cm}^{-3}$ . The intensity data were collected with the  $\theta/2\theta$  scanning mode. A total of 2661 independent reflections were measured with  $2\theta$  values below  $130^\circ$ , of which 1865 reflections were considered as observed by the criterion  $I > 3\sigma(I)$ , where  $\sigma(I)$  was determined from counting statistics. The intensity data were reduced to structure amplitudes by the application of Lorentz and polarization factors, and no absorption corrections were applied.

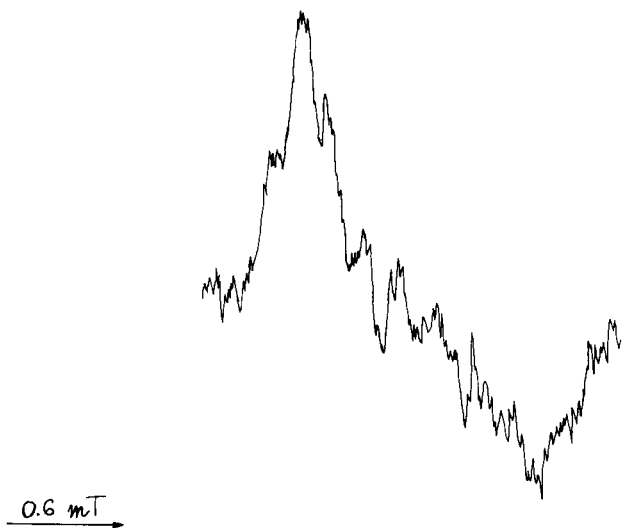


Figure 2

The observed esr spectrum of the 4'-dimethylamino-10-phenylpyrido[3,2-*b*]benzothiazinium cation radical as  $1 \times 10^{-3} M$  solution in 80% aqueous sulfuric acid.

The structure was solved by the application of direct methods with the weighed multisolution tangent-refinement program, MULTAN 78 [7]. The E map showed the positions of all non-hydrogen atoms. The refinements were carried out by full-matrix least-squares method using the SHELX system of programs [8]. The anisotropic temperature factors were used for non-hydrogen atoms. All hydrogen atoms were located in a difference Fourier synthesis and the isotropic temperature factors were used for hydrogen atoms in the refinement. The weight of the reflection was assigned as  $1/[\sigma(F)]^2$ , where  $\sigma(F)$  was calculated from counting statistics. The quantity  $\Sigma w(|F_o| - |F_c|)^2$  was minimized. The final R index,  $\Sigma ||F_o| - |F_c|| / \Sigma |F_o|$ , was 0.050 and the weighted disagreement index was 0.057 for 1865 observed reflections. The final difference Fourier synthesis showed a maximum residue of electron density of  $0.23 e \text{ \AA}^{-3}$ . The atomic scattering factors used for sulfur, nitrogen, carbon, and hydrogen were those from International Tables for X-ray Crystallography [9]. The final atomic parameters are given in Table 1.

The esr spectra shown in Figures 1 and 2 were recorded in 80% aqueous sulfuric acid at the scan range of 100 G and field setting of 3375 G with modulation frequency of 100 KHz. The scanning was done at room temperature with the power of 20 mW and microwave frequency of 9.460 GHz. The setting for modulation amplitude and receiver gain were  $1.6 \times 10^{-1}$  and  $1 \times 10^4$ , respectively. The scan time was 4 minutes.

## Results and Discussion.

The identification of the atoms and the configuration of the molecule are shown in ORTEP [10] drawing in Figure 3. The bond lengths and bond angles, with their standard

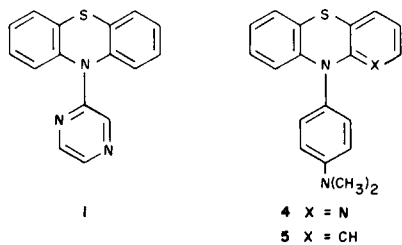


Figure 4

Bond lengths ( $\text{\AA}$ ) (a) and bond angles ( $^\circ$ ) (b) of **4** with e.s.d.'s in parentheses.

deviations, are shown in Figure 4. The least-squares planes of the benzo, pyrido, and phenyl rings, together with the deviations of the atoms from the planes are also shown in Figure 3. The central ring is in a boat conforma-

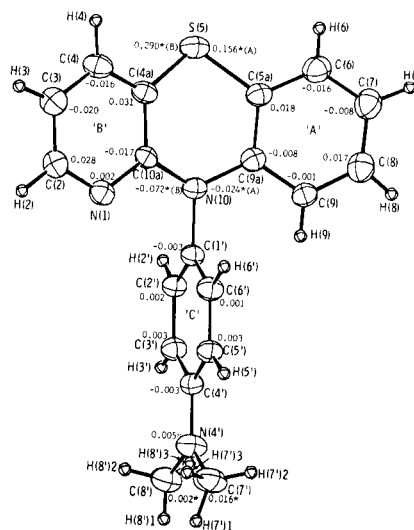


Figure 3

ORTEP drawing of a molecule of **4** with the deviations of atoms from the least-squares planes shown in  $\text{\AA}$  units. The equations for the planes are:  
 Plane 'A'  $5.05(1)x - 5.10(1)y + 10.10(3)z = 3.25$  (1)  
 Plane 'B'  $1.66(1)x - 5.25(1)y + 15.69(2)z = 3.77(1)$   
 Plane 'C'  $-7.04(1)x + 0.75(1)y + 14.18(2)z = 2.48(1)$

where  $x$ ,  $y$ , and  $z$  are in fractional coordinates. Dihedral angles between 'A' and 'B'  $154.1(1)^\circ$ , 'A' and 'C'  $101.8(1)^\circ$ , 'B' and 'C'  $103.8(1)^\circ$ . An asterisk indicates atoms excluded from the calculation of the least-squares planes. The lettering in parentheses indicates the plane that the deviation is from.

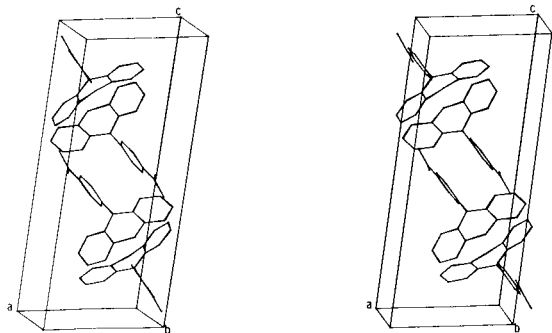
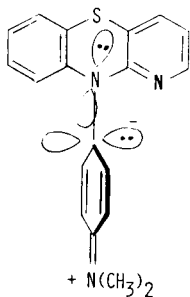


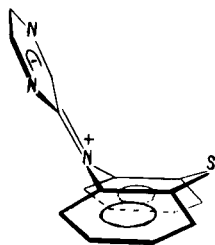
Figure 5

Stereoscopic drawing of molecular packing of **4**, excluding hydrogen atoms, in the unit cell.

tion as shown by the torsion angles around the central ring and the puckering parameters [11] in Table 2. The folding angle between the planes of the benzo and pyrido rings is  $154.1(1)^\circ$ . The phenyl ring is in a boat equatorial conformation with respect to the central ring of the pyridobenzothiazine ring system. The plane of the phenyl ring nearly bisects the pyridobenzothiazine ring with the dihedral angles of  $101.8(1)^\circ$  between the planes of phenyl and benzo rings and  $103.8(1)^\circ$  between the planes of phenyl and pyrido rings. The bisecting conformation can be shown also by the torsion angles about the N(10)-C(1') bond in Table 2. The folding angle in **4** has similar magnitude as those observed in 10-(*o*-methoxyphenyl)phenothiazine, [12] and 10-(*p*-bromophenyl)phenothiazine, [13] 10-(2'-nitrophenyl)phenothiazine, [14] and 10-(2'-methoxyphenyl)pyrido[3,2-*b*][1,4]benzothiazine [15]. In all these structures, the plane of the phenyl ring is bisecting the tricyclic ring system. However, the folding angle of  $132.2^\circ$  in 10-(2'-pyrazyl)phenythiazine, **1**, [2], is much smaller than that observed in **4** due to the fact that the plane of the pyrazine ring in **1** is perpendicular to the plane bisecting the dihedral angle of the phenothiazine nucleus. There is electronic interaction between the 10-pyrazyl substituent and the phenothiazine ring system in compound **1** due to the electron withdrawing 10-pyrazyl substituent. On the contrary, the (4'-dimethylamino)-10-phenyl group in **4** is an



4b



1a

electron releasing substituent and creates the increase of electron density on C(1') as shown in **4b**. Therefore, the plane of the phenyl ring is parallel to the plane bisecting the pyridobenzothiazine ring so that the p orbital of C(1') is perpendicular to that of N(10) in order to minimize the electronic repulsion between the p-orbitals and N(10) lone pair of electrons. The repulsion between the two ring systems can be further demonstrated by the bond length of  $1.456(4)\text{\AA}$  between N(10) and C(1'), which is longer, for example, than that of  $1.436(2)\text{\AA}$  and  $1.439(4)\text{\AA}$  in 10-(*o*-methoxyphenyl)phenothiazine [12] and 10-(2'-methoxyphenyl)pyrido[3,2-*b*][1,4]benzothiazine, [15], respectively. The longer N(10)-C(1') bond length in **4** is attributed to the stronger electron releasing dimethylamino substituent.

Furthermore, the delocalization of the lone pair of electrons from N(1) of the pyrido ring prevents any acceptance of electron density to the pyridobenzothiazine ring system from the 10-(4'-dimethylamino)phenyl substituent. This can be shown by the shorter N(1)-C(10a) bond length of  $1.344(4)\text{\AA}$  in **4**. The N(10)-C(1') bond length in **1** is  $1.388(3)\text{\AA}$  and the electronic interaction takes place between the two ring systems (**1a**) since the pyrazine ring is an electron withdrawing group.

The dimethylamino group is nearly coplanar with the phenyl ring as indicated in Figure 3 and by the torsion angles about C(4')-N(4') bond in Table 2. The C(7') is out of the plane of the phenyl ring by  $0.161(6)\text{\AA}$  due apparently to the nonbonded interaction between the two methyl groups.

The packing of the molecules in the unit cell is shown in the stereoscopic drawing in Figure 5. There is no intermolecular distances less than van der Waals separation.

Thus, the crystal structure of **4** validates our previous findings and shows the lack of electronic interactions for **4** in the solid state. The fact that **4a** does not form the Wurster type radical is not surprising since N(1) acts as a powerful -I substituent and competes effectively with the -N(CH<sub>3</sub>)<sub>2</sub> group for the paramagnetic electron. The unpaired spin is delocalized onto the  $\pi$ -deficient pyridine where structures such as **4a** contribute to the overall stability of cation radical of **4**.

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