The Structures of Two Nitro-Substituted Phenoxathiins: 1-Nitrophenoxathiin and 9-Nitro-1-azaphenoxathiin

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Abstract

The structures of two nitro-substituted phenoxathiin derivatives have been determined by single-crystal X-ray diffraction. 1-Nitrophenoxathiin, $C_{12}H_7NO_3S$, is monoclinic, $P2_1$, with $a = 13\cdot864$ (3), $b = 7\cdot160$ (2), $c = 10\cdot950$ (2) Å, $\beta = 111\cdot20$ (3)° at 138 K and $Z = 4$. The final R factor is 0·033 for 2250 diffractometer data measured at 138 (2) K using Cu $K\bar{\alpha}$ radiation. The two molecules in the asymmetric unit are distinctly different in their folding about the central S–O vector. The dihedral angle between the non-central rings is 163·8° in molecule *A*, and 145·7° in molecule *B*. In molecule *A*, the orientation of the nitro group indicates an intramolecular non-bonding S···O interaction (2·606 Å), while in molecule *B* the nitro group is rotated out of the plane of the benzene ring creating a less favorable situation for such an interaction. 9-Nitro-1-azaphenoxathiin, $C_{11}H_6N_2O_3S$, is orthorhombic, $Pbc2_1$, with $a = 3\cdot799$ (1), $b = 19\cdot940$ (4), $c = 25\cdot874$ (8) Å at 138 K and $Z = 8$. The final R factor is 0·082 for 2057 diffractometer data measured at 138 (2) K using Cu $K\bar{\alpha}$ radiation. Both of the molecules in the asymmetric unit are nearly planar; the dihedral angle between the non-central rings is 178·2° for molecule *A* and 177·1° for molecule *B*. In both molecules, there are indications of non-bonding S···O interactions (S···O distances of 2·590 and 2·570 Å) which may help stabilize the near-planar conformations. However, the planarity of the tricyclic system in the present structure may primarily be due to the aza substitution at the 1-position.

Introduction

The compounds 1-nitrophenoxathiin (Turley & Martin, 1981) and 9-nitro-1-azaphenoxathiin (Martin & Turley, 1978) were recently synthesized. Both compounds are derivatives of phenoxathiin, a hetero tricyclic system having a folded molecular geometry quite similar to a number of pharmacologically active phenothiazines. Early investigators concluded that the differences in pharmacological activity among the various phenothiazine derivatives were attributable either to the dihedral angle between the non-central rings or to the change in substituent location or both. Recent work (Martin, Korp, Turley & Bernal, 1978) on some aza-substituted phenoxathiins demonstrated that active derivatives have approximately the same dihedral angle as exhibited by their inactive counterparts. It was therefore suggested that activity is related more to the substituent location in the parent molecule than to the difference in dihedral angle. The effect of substitution on the molecular geometry (dihedral angle in particular) is also of interest.

The structure determinations of the two nitro-substituted phenoxathiin derivatives are part of a continuing study on the effect of substitution pattern on the geometry of the parent molecule, phenoxathiin. It is expected that such studies will provide better understanding of the correlation between the pharmacological activity and molecular configuration and structure.

Experimental

Crystals of both 1-nitrophenoxathiin (NPX) and 9-nitro-1-azaphenoxathiin (NAPX) are bright-red, prismatic needles. The unit-cell dimensions and intensity data for both compounds were obtained at 138 (2) K using a Nonius CAD-4 counter diffractometer controlled by a PDP8/e computer and fitted with a low-temperature device.

Table 1. *Crystal data of* 1-*nitrophenoxathiin and* 9-*nitro-*1-*azaphenoxathiin*

	1-Nitrophenoxathiin		9-Nitro-1-azaphenoxathiin	
Formula	$C_{12}H_7NO_3S$		$C_{11}H_6N_2O_3S$	
M_r	245·3		246·2	
Space group	$P2_1$		$Pbc2_1$	
Cell parameters	138 K	293 K	138 K	293 K
a (Å)	13·864 (3)	13·949 (2)	3·799 (1)	3·900 (2)
b (Å)	7·160 (2)	7·305 (2)	19·940 (4)	19·924 (7)
c (Å)	10·950 (2)	10·990 (1)	25·874 (8)	26·000 (11)
β (°)	111·20 (3)	111·09 (1)		
V (Å³)	1013·7	1044·8	1960·0	2020·3
Z	4		8	
ρ_c (Mg m⁻³)		1·559		1·618
ρ_m (Mg m⁻³)		1·564		1·610
Radiation	Cu $K\alpha_1$ (cell) ($\lambda = 1·54051$ Å)		Cu $K\alpha_1$ (cell) ($\lambda = 1·54051$ Å)	
	Cu $K\bar{\alpha}$(data) ($\lambda = 1·54178$ Å)		Cu $K\bar{\alpha}$(data) ($\lambda = 1·54178$ Å)	
Crystal dimensions (mm)	0·60 × 0·19 × 0·05		0·19 × 0·06 × 0·03	
μ (Cu $K\alpha$) (mm⁻¹)	2·74		2·87	
Scan type	θ–2θ		θ–2θ	
Scan width (°)	(0·90 + 0·15 tan θ)		(1·10 + 0·14 tan θ)	
Aperture width (mm)	(3·5 + 0·86 tan θ)		(4·5 + 0·86 tan θ)	
Crystal–counter distance (mm)	173		173	
Maximum counting time (s)	40		60	
Data range (°)	$2\theta \le 150$		$2\theta \le 150$	
Unique data	2250		2057	
Unique data with $I > 2\sigma(I)$	2189		1704	

Unit-cell parameters were determined by least-squares fit to $+2\theta$ and -2θ values of a number of reflections (48 for NPX, and 16 for NAPX) measured at 138 and 293 K, using Cu $K\alpha_1$ ($\lambda = 1·54051$ Å) radiation. The space group in each case was determined from the systematic absences ($0k0$, $k = 2n + 1$, for NPX, and $0kl$, $k = 2n + 1$, $h0l$, $l = 2n + 1$, for NAPX). The density for each compound was measured by flotation in an aqueous $AgNO_3$ solution. For both compounds, intensities of all reflections with $2\theta \le 150°$ were measured at low temperature using Cu $K\bar{\alpha}$ radiation and applying θ–2θ scan techniques. The maximum change in the intensity of the monitor reflection was less than 4% for both compounds. Crystal data and relevant parameters for intensity measurements are given in Table 1.

The data were scaled by means of standard reflections and Lorentz and polarization corrections were applied in the usual way. In each case, a Gaussian method (Coppens, Leiserowitz & Rabinovich, 1965) was employed to make the absorption correction by using 216 sampling points. Each structure amplitude was assigned an experimental weight, $w_F = 1/\sigma_F^2$, where σ_F was obtained from the counting statistics (Ealick & van der Helm, 1975).

Structure determination and refinement

1-*Nitrophenoxathiin*

The positions of the two S atoms were determined from a three-dimensional Patterson map. All 32

non-hydrogen atoms in the asymmetric unit (two molecules) were obtained by successive difference Fourier syntheses. The least-squares refinement of the structure was carried out in stages, using isotropic and then anisotropic thermal parameters. All 14 H atoms were located from a difference Fourier map and were refined isotropically. The final R factor is 0·031 for 2173 reflections included in the least-squares calculations, and 0·033 for all 2250 reflections.

9-*Nitro-*1-*azaphenoxathiin*

The structure was solved by direct methods using the program *MULTAN* (Germain, Main & Woolfson, 1971). All non-hydrogen atoms of the two molecules in the asymmetric unit were refined first isotropically, then with anisotropic thermal parameters. All H atoms

Table 2. *Positional parameters* ($\times 10^4$) *and equivalent isotropic thermal parameters* (Å² $\times 10^4$) *of non-hydrogen atoms in* 1-*nitrophenoxathiin*

Calculated standard deviations for the last digit are in parentheses.

$$U_{eq} = (\tfrac{1}{3}\pi^2) \sum_i \sum_j b_{ij} \mathbf{a}_i \cdot \mathbf{a}_j.$$

	x	y	z	U_{eq}
Molecule A				
S	4283·5 (4)	−72·0 (12)	472·6 (6)	229 (3)
C(1)	6017 (2)	−585 (4)	2734 (2)	203 (11)
C(2)	7057 (2)	−779 (4)	3460 (2)	237 (11)
C(3)	7757 (2)	−735 (5)	2823 (3)	257 (11)
C(4)	7394 (2)	−495 (4)	1473 (3)	235 (11)
C(4a)	6354 (2)	−285 (4)	767 (2)	201 (10)
O(5)	6125·5 (13)	58 (3)	−547 (2)	260 (9)
C(5a)	5145 (2)	−257 (4)	−1463 (2)	211 (10)
C(6)	5073 (2)	−448 (4)	−2751 (2)	244 (11)
C(7)	4111 (2)	−716 (5)	−3733 (2)	263 (11)
C(8)	3227 (2)	−825 (5)	−3412 (2)	252 (11)
C(9)	3309 (2)	−639 (4)	−2110 (2)	225 (11)
C(9a)	4266 (2)	−337 (4)	−1135 (2)	197 (10)
C(10a)	5610 (2)	−327 (4)	1365 (2)	186 (10)
N	5324 (2)	−616 (4)	3474 (2)	247 (10)
O(1)	4409·2 (14)	−268 (4)	2902 (2)	330 (10)
O(2)	5693 (2)	−993 (5)	4644 (2)	414 (11)
Molecule B				
S	−1121·7 (4)	3418·2 (12)	664·8 (6)	208 (2)
C(1)	578 (2)	2340 (4)	2852 (2)	218 (11)
C(2)	1593 (2)	1815 (4)	3505 (3)	255 (11)
C(3)	2271 (2)	1850 (4)	2833 (3)	264 (11)
C(4)	1913 (2)	2380 (4)	1527 (3)	248 (11)
C(4a)	893 (2)	2861 (4)	886 (2)	190 (10)
O(5)	617·5 (13)	3447 (3)	−399 (2)	223 (7)
C(5a)	−331 (2)	2861 (4)	−1280 (2)	201 (10)
C(6)	−400 (2)	2413 (4)	−2535 (3)	235 (11)
C(7)	−1353 (2)	1913 (4)	−3460 (2)	251 (11)
C(8)	−2226 (2)	1835 (4)	−3116 (2)	240 (11)
C(9)	−2146 (2)	2261 (4)	−1842 (3)	228 (11)
C(9a)	−1195 (2)	2790 (4)	−923 (2)	186 (10)
C(10a)	185 (2)	2857 (4)	1532 (3)	191 (10)
N	−97 (2)	2376 (4)	3618 (2)	278 (11)
O(1)	−882·4 (14)	3335 (4)	3211 (2)	324 (9)
O(2)	170 (2)	1474 (5)	4642 (2)	455 (13)

except for five were obtained from a difference map. The refinement converged to an R factor of 0·068 for 1704 reflections that were included in the least-squares calculations and 0·082 for all 2057 reflections.

Refinements for both structures were carried out by using a block-diagonal least-squares program (Ahmed, 1966) in which the quantity $\sum w_F(|kF_o| - |F_c|)^2$ was minimized. For each structure, the anomalous-dispersion effect by the S atom was included, and the polarity of the structure was ascertained by applying the $\mathcal{R}$ method of Hamilton (1965). The maximum parameter shift in the final cycle of least-squares refinement was less than 25% of the corresponding standard deviation in NPX and less than 30% for NAPX. The scattering factors for O, C, N and S atoms and f' and f'' values for S were taken from *International Tables for X-ray Crystallography* (1974). H-atom scattering factors were taken from Stewart, Davidson & Simpson (1965).

Table 3. *Positional parameters* ($\times 10^4$) *and equivalent isotropic thermal parameters* (Å^2) *of non-hydrogen atoms for* 9-nitro-1-azaphenoxathiin

Estimated standard deviations for the last digits are in parentheses.

	x	y	z	U_{eq}
Molecule A				
S	7692 (6)	7885·5 (9)	327·0 (7)	0·0292 (8)
O(5)	7931 (17)	8012 (3)	1548 (2)	0·037 (3)
O(1)	5476 (18)	6861 (3)	−194 (2)	0·040 (3)
O(2)	2085 (19)	6042 (3)	44 (3)	0·047 (4)
N(1)	10442 (20)	9074 (3)	457 (2)	0·034 (4)
N(2)	4015 (20)	6522 (3)	133 (2)	0·032 (4)
C(1a)	9194 (21)	8551 (4)	723 (2)	0·029 (4)
C(2)	11708 (23)	9599 (4)	711 (3)	0·033 (4)
C(3)	11816 (24)	9622 (4)	1251 (3)	0·036 (4)
C(4)	10502 (25)	9076 (4)	1525 (3)	0·034 (4)
C(4a)	9189 (21)	8535 (4)	1262 (2)	0·029 (4)
C(5a)	6479 (20)	7451 (4)	1339 (2)	0·028 (4)
C(6)	5262 (24)	6998 (4)	1702 (2)	0·033 (4)
C(7)	3708 (23)	6407 (4)	1566 (2)	0·033 (4)
C(8)	3356 (22)	6245 (4)	1042 (3)	0·030 (4)
C(9)	4547 (22)	6721 (4)	682 (2)	0·028 (4)
C(9a)	6086 (21)	7321 (4)	800 (2)	0·027 (4)
Molecule B				
S	7829 (5)	8946·2 (9)	7851·9 (7)	0·0292 (8)
O(5)	7873 (15)	8519 (3)	9036 (2)	0·035 (3)
O(1)	5425 (18)	10043 (3)	7468 (2)	0·045 (3)
O(2)	2347 (19)	10832 (3)	7812 (2)	0·053 (4)
N(1)	10687 (19)	7770 (3)	7818 (2)	0·034 (3)
N(2)	4023 (19)	10314 (3)	7842 (2)	0·035 (3)
C(1a)	9382 (23)	8207 (4)	8151 (2)	0·029 (4)
C(2)	12067 (27)	7198 (4)	7995 (3)	0·041 (5)
C(3)	12129 (26)	7045 (4)	8527 (3)	0·040 (5)
C(4)	10662 (24)	7496 (4)	8864 (3)	0·038 (4)
C(4a)	9246 (22)	8078 (4)	8681 (2)	0·031 (4)
C(5a)	6266 (22)	9107 (4)	8900 (2)	0·030 (4)
C(6)	4889 (24)	9458 (4)	9317 (2)	0·036 (4)
C(7)	3206 (23)	10062 (4)	9249 (3)	0·037 (4)
C(8)	3043 (24)	10354 (4)	8762 (3)	0·036 (4)
C(9)	4414 (24)	9990 (4)	8348 (2)	0·029 (4)
C(9a)	6095 (24)	9376 (4)	8391 (2)	0·029 (4)

The final atomic parameters for the two structures are listed in Tables 2 and 3 respectively.*

Description of the structures

1-Nitrophenoxathiin

Fig. 1 shows a stereoscopic side view of the two crystallographically independent molecules of NPX. The numbering schemes and the bond lengths in the two molecules are given in Fig. 2. Bond angles are listed in Table 4.

There are some significant geometrical differences between the two independent molecules in the asymmetric unit. Neither molecule is planar. The two non-central rings are planar to within limits of error (Table 5), but they are folded about the central S–O axis. The dihedral angle between the non-central rings is 163·8° in molecule A and 145·7° in molecule B. There are no significant differences in the bond lengths in the two molecules. The difference in fold angle between the two molecules is correlated with the observation that all the endocyclic bond angles of the central ring are larger in molecule A when compared to
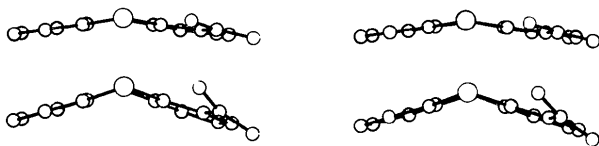
Fig. 1. A stereoscopic side view of the two molecules A (upper) and B (lower) of 1-nitrophenoxathiin. (This does not represent the way they are stacked, see Fig. 3.)
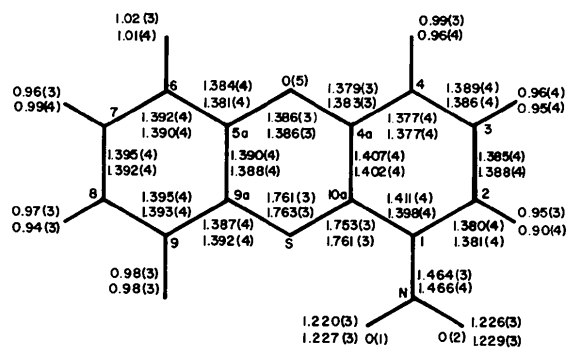

Fig. 2. Bond lengths (Å) in 1-nitrophenoxathiin. Upper values are for molecule A, lower values for molecule B. The e.s.d.'s are in parentheses.

Table 4. *Bond angles* (°) *in NPX*

	Molecule A	Molecule B
C(10a)—S—C(9a)	100·3 (1)	99·0 (1)
C(5a)—O(5)—C(4a)	121·4 (2)	117·4 (2)
C(1)—N—O(1)	118·8 (2)	117·9 (2)
C(1)—N—O(2)	118·1 (2)	117·9 (3)
O(1)—N—O(2)	123·1 (2)	124·1 (3)
N—C(1)—C(2)	116·0 (2)	116·8 (2)
N—C(1)—C(10a)	119·9 (2)	119·7 (2)
C(2)—C(1)—C(10a)	124·1 (2)	123·5 (3)
C(3)—C(2)—C(1)	118·9 (3)	118·6 (3)
C(2)—C(3)—C(4)	119·3 (3)	119·5 (3)
C(3)—C(4)—C(4a)	121·0 (3)	120·9 (3)
C(4)—C(4a)—C(10a)	122·1 (3)	121·3 (3)
C(4)—C(4a)—O(5)	113·8 (2)	116·7 (2)
C(10a)—C(4a)—O(5)	124·0 (2)	121·8 (2)
O(5)—C(5a)—C(9a)	122·8 (2)	120·9 (2)
O(5)—C(5a)—C(6)	116·3 (2)	118·0 (2)
C(9a)—C(5a)—C(6)	120·8 (3)	121·0 (3)
C(5a)—C(6)—C(7)	119·8 (3)	119·4 (4)
C(6)—C(7)—C(8)	119·8 (3)	120·3 (3)
C(7)—C(8)—C(9)	119·8 (3)	120·0 (3)
C(8)—C(9)—C(9a)	120·3 (3)	119·7 (3)
C(5a)—C(9a)—C(9)	119·4 (2)	119·6 (3)
C(5a)—C(9a)—S	123·8 (2)	121·3 (2)
C(9)—C(9a)—S	116·8 (2)	119·0 (2)
C(1)—C(10a)—C(4a)	114·7 (2)	116·1 (2)
C(1)—C(10a)—S	122·9 (2)	124·0 (2)
C(4a)—C(10a)—S	122·4 (2)	119·9 (2)

Table 5. *Least-squares planes and atomic deviations*

Equation of the plane: $AX + BY + CZ = D$, where x,y,z are fractional coordinates. Standard deviations for the last digit are in parentheses.

Plane	A	B	C	D
(i) NPX				
C(1), C(2), C(3), C(4), C(4a), C(10a)				
1(A)	0·576	7·093	1·146	0·248
1(B)	1·943	6·822	2·192	2·324
C(5a), C(6), C(7), C(8), C(9), C(9a)				
2(A)	1·117	−7·078	0·963	0·613
2(B)	1·504	−6·858	2·279	−2·300

Dihedral angle between 1(A) and 2(A): 163·8 (4)°
Dihedral angle between 1(B) and 2(B): 145·7 (4)°

(ii) NAPX
N(1), C(1a), C(2), C(3), C(4), C(4a)

	A	B	C	D
1(A)	3·453	−8·315	−0·209	−3·951
1(B)	3·384	8·859	2·462	12·435
C(5a), C(6), C(7), C(8), C(9), C(9a)				
2(A)	3·406	−8·832	0·022	−4·383
2(B)	3·330	9·178	3·627	13·677

Dihedral angle between 1(A) and 2(A): 178·2 (14)°
Dihedral angle between 1(B) and (2B): 177·1 (14)°

Deviations (Å) of atoms from the planes

	Planes			
	1(A)	1(B)	2(A)	2(B)
NPX				
S	0·002 (1)	−0·064 (1)	−0·038 (1)	−0·061 (1)
O(5)	0·083 (2)	0·060 (2)	−0·023 (2)	−0·062 (2)
NAPX				
S	0·043 (2)	0·074 (2)	0·039 (2)	−0·010 (2)
O(5)	−0·005 (6)	0·002 (6)	0·011 (6)	0·042 (6)

Table 6. *Torsion angles* (°) *in the 'five-membered ring'*

Standard deviations for the last digit are in parentheses.

				1-Nitrophenoxathiin		9-Nitro-1-azaphenoxathiin	
				Molecule A	Molecule B	Molecule A	Molecule B
S	1	2	N	−1·1 (4)	−4·5 (4)	−2·4 (11)	−0·3 (12)
1	2	N	O	−5·8 (4)	−20·3 (4)	11·0 (11)	−4·5 (12)
2	N	O	S	6·9 (3)	23·8 (3)	−10·7 (8)	5·2 (8)
N	O	S	1	−6·0 (2)	−20·9 (2)	7·9 (5)	−4·4 (5)
O	S	1	2	3·4 (2)	12·4 (2)	−2·6 (7)	2·3 (7)

those in molecule B. There does not appear to be a systematic trend in the deviations of the S and O atoms from least-squares planes of the non-central rings (Table 5). The average of the four C—S bonds in the structure is 1·760 (3) Å, which is comparable to that in NAPX, but the average of the four C—O bonds of 1·384 (3) Å in the present structure is larger than that observed in NAPX [1·367 (10) Å].

The nitro group is rotated out of the plane of the benzene ring to which it is attached. The dihedral angle that the plane of the nitro group makes with the attached benzene ring is 5·8° in molecule A while it is 20·3° in molecule B. This increased rotation of the nitro group in molecule B is reflected in the large differences in the torsion angles for the so-called 'five-membered ring' consisting of S, C(10a), C(1), N and O(1). These angles are given in Table 6.

The orientation of the nitro group results in S···O(1) distances of 2·606 Å in molecule A and 2·687 Å in molecule B. The two N—O distances in the nitro group are approximately equal, 1·220 (3) and 1·227 (3) Å in molecule A, and 1·226 (3) and 1·229 (3) Å in molecule B. The angle O—N—O is 123·1 (3)° in molecule A and 124·1 (3)° in molecule B.

The packing scheme in the crystal structure of 1-nitrophenoxathiin is shown in Fig. 3. The approximate mid-point of molecule A lies on the screw axis at ($\frac{1}{4},y,0$) and that of molecule B on the screw axis at (0,y,0) with their flat faces lying perpendicular to the crystallographic b axis. Both molecules thus form parallel stacks along the b axis with an average
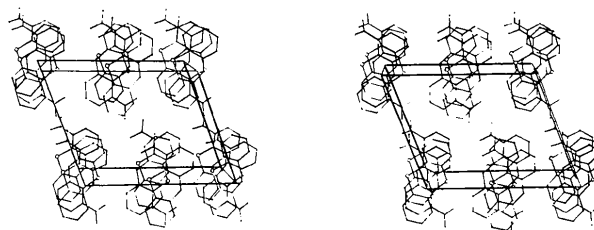

Fig. 3. Packing scheme in the 1-nitrophenoxathiin structure.

stacking separation of $b/2$ (3·58 Å). However, due to dissimilar folding of the two molecules, the separation distances between the parallel planes in the two molecules are significantly different, 3·55 Å for molecules A and 3·43 Å for molecules B. Beside this difference, the overall packing shows that the orientations and the environments of the two molecules are quite similar. There are no unusually short intermolecular distances. Therefore, packing forces alone can hardly be responsible for the large difference (18°) in the dihedral angle in the two molecules. Differences in dihedral angles within the same structure are encountered relatively frequently in similar tricyclic compounds: 9·5° in 2-azaphenoxathiin 2-oxide (Caldwell *et al.*, 1981), 6·6° in triflupromazine (Phelps & Cordes, 1974), 10·7° in *N*-isopropylphenothiazine (Chu & van der Helm, 1976). However, the difference observed in the present structure is by far the largest reported.

9-Nitro-1-azaphenoxathiin

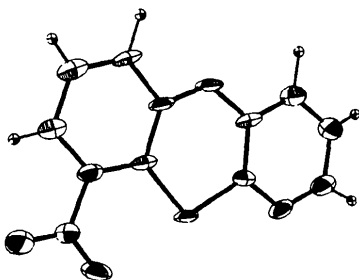A view of one of the two crystallographically independent molecules is shown in Fig. 4. The

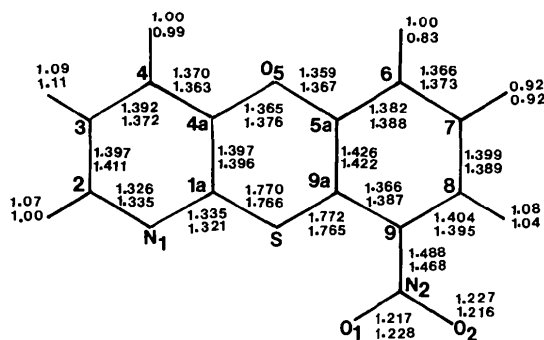Fig. 4. A drawing of one of the independent molecules of 9-nitro-1-azaphenoxathiin.

Fig. 5. Bond lengths (Å) in 9-nitro-1-azaphenoxathiin. Upper values are for molecule A and lower values for molecule B. The standard deviations are between 0·007 and 0·011 Å for bonds involving non-hydrogen atoms and 0·08 Å for bonds involving H atoms.

numbering scheme and the bond lengths are shown in Fig. 5. Bond angles in the two molecules are listed in Table 7.

The two molecules have the same configuration and, within experimental error, they are dimensionally equivalent. The mean value of the four C—S bonds is 1·768 (7) Å and the mean of the four C—O bonds is 1·367 (10) Å.

The molecule of 9-nitro-1-azaphenoxathiin is flat with all the non-hydrogen atoms lying approximately in a plane (r.m.s. deviation of 14 atoms is 0·03 Å in both molecules A and B). The major deviations from the least-squares planes are in the nitro group which is slightly rotated out of the planes of the molecules. The dihedral angle between the plane of the nitro group [C(9), N, O(1) and O(2)] and the benzene ring is 11·0° in molecule A and 4·5° in molecule B. This difference is also reflected by the deviations of the atoms O(1) and O(2) from the mean plane of the molecule, which are 0·20 and 0·24 Å in molecule A, and 0·11 and 0·10 Å in molecule B respectively. In both molecules, the non-central rings are planar to within limits of error (Table 5). The dihedral angle between the two non-central rings in molecule A is 178·2°, and 177·1° for molecule B, giving almost negligible folding along the S—O vector of the central ring in contrast with the much larger fold angles in 1-nitrophenoxathiin and other related compounds discussed in a later section.

Table 7. *Bond angles* (°) *in NAPX*

	Molecule A	Molecule B
C(1a)—S—C(9a)	100·8 (3)	100·6 (4)
C(4a)—O(5)—C(5a)	123·7 (6)	123·0 (6)
C(1a)—N(1)—C(2)	119·3 (7)	119·2 (7)
C(9)—N(2)—O(1)	117·1 (6)	117·7 (6)
O(1)—N(2)—O(2)	125·0 (7)	123·5 (7)
C(9)—N(2)—O(2)	117·9 (6)	118·8 (7)
S—C(1a)—N(1)	113·7 (5)	113·0 (6)
S—C(1a)—C(4a)	124·0 (6)	124·9 (6)
N(1)—C(1a)—C(4a)	122·2 (7)	122·1 (7)
N(1)—C(2)—C(3)	122·2 (7)	121·7 (8)
C(2)—C(3)—C(4)	118·2 (8)	118·1 (8)
C(3)—C(4)—C(4a)	119·7 (7)	119·8 (8)
C(4)—C(4a)—O(5)	117·5 (7)	117·4 (7)
C(4)—C(4a)—C(1a)	118·4 (7)	119·0 (7)
O(5)—C(4a)—C(1a)	124·1 (7)	123·6 (7)
O(5)—C(5a)—C(6)	113·7 (6)	113·6 (7)
O(5)—C(5a)—C(9a)	125·6 (7)	125·6 (7)
C(6)—C(5a)—C(9a)	120·7 (7)	120·7 (7)
C(5a)—C(6)—C(7)	122·2 (7)	121·2 (7)
C(6)—C(7)—C(8)	119·4 (7)	120·2 (8)
C(7)—C(8)—C(9)	117·1 (7)	117·6 (7)
C(8)—C(9)—C(9a)	125·5 (7)	124·6 (7)
C(8)—C(9)—N(2)	114·1 (6)	114·8 (7)
N(2)—C(9)—C(9a)	120·3 (7)	120·5 (7)
C(9)—C(9a)—S	123·3 (6)	122·4 (6)
C(9)—C(9a)—C(5a)	115·0 (7)	115·4 (7)
S—C(9a)—C(5a)	121·6 (6)	122·1 (6)

The nitro groups in both molecules are held in such a position that atom O(1) is close to the S atom with S⋯O(1) distances of 2·590 and 2·570 Å in molecules A and B respectively. The planarity of the five atoms S, C(9a), C(9), N(2) and O(1) can be appreciated from the torsion angles of the so-called 'five-membered' ring given in Table 6. There are some significant differences in the torsion angles in the two molecules, arising from the dissimilar rotation of the nitro group with respect to the plane of the attached benzene ring.
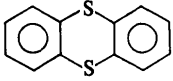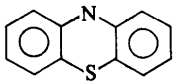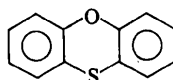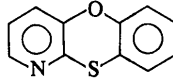
The N(2)—O(1) bond lengths are 1·217 (8) and 1·228 (9) Å in the two molecules, while the N(2)—O(2) bond lengths are 1·227 (9) and 1·216 (9) Å. The mean value of the C(9)—N(2)—O(1) angle is 117·4 (6)° and that for the C(9)—N(2)—O(2) angle is 118·3 (6)°. O—N—O bond angles for molecules A and B are 125·0 (7) and 123·5 (7)° respectively. The C—N(2) bond lengths of 1·488 (9) and 1·468 (9) Å are in good agreement with that of a pure single bond (Eichhorn, 1956). The mean value of the four C—N(1) bonds is 1·329 (10) Å. The crystal structure of 9-nitro-1-aza-

phenoxathiin is characterized by a short crystallographic a axis (3·799 Å). The molecules are oriented with their flat faces nearly perpendicular to the a axis and with their longest direction parallel to the c axis.

Discussion

A large variety of hetero tricyclic compounds can be derived if either one or both of the two anthracene meso CH groups are replaced by other atoms (A and B). It has been suggested (Hosoya, 1963) that molecules are planar if both A and B are any of C, N or O, but folded if at least one of A and B is a S atom. According to Lynton & Cox (1956) and Hosoya (1963), this is explained by assuming the participation of d orbitals in the bonding of the S atom. The valence orbitals in the atoms C, N and O are limited to 2s and 2p or hybrids of the two, but S can be promoted to the configuration $(3s)^2(3p)^3(3d)$. The folding of the molecule is due to the 'natural' valency angle of the S atom. In recent years, a

Table 8. *Comparison of some structural features in hetero tricyclic systems*

	C–S (Å)	C–S–C (°)	C–X–C (°)	Dihedral angle (°)	Reference
(i) : Thianthrene and derivatives					
Thianthrene				128	(a)
α-Thianthrene dioxide				123	(b)
β-Thianthrene dioxide				122	(c)
Thianthrene tetroxide				127	(d)
(ii) : Phenothiazine and derivatives					
Phenothiazine	1·770 (3)	99·6 (2)	121·5 (2)	153·3	(e)
N-Methylphenothiazine	1·764 (2)	97·4 (1)	118·0 (2)	143·7	(f)
N-Ethylphenothiazine	1·766 (3)	97·4 (1)	116·7 (2)	135·0	(g)
Chlorpromazine	1·75 (1)	97·3 (3)	118·4 (5)	139·4	(h)
Thiethylperazine	1·78 (2)	99·0 (7)	118·1 (10)	139·0	(i)
Triflupromazine	1·755 (8)	97·9 (4)	115 (1)	134·4	(j)
	1·733 (8)	96·5 (4)	117 (1)	141·0	
Promethazine	1·766 (5)	98·8 (2)	118·5 (4)	140·6	(k)
Methoxypromazine	1·758 (7)	99·8 (3)	122·3 (5)	157·4	(l)
N-Isopropylphenothiazine	1·761 (1)	97·3 (1)	117·4 (1)	136·1	(m)
	1·760 (1)	98·9 (1)	118·6 (1)	146·8	
(iiia) : Phenoxathiin and derivatives					
Phenoxathiin	1·752 (43)	97·68 (3)	117·63 (5)	138·4	(n)
1-Nitrophenoxathiin	1·757 (3)	100·3 (1)	121·4 (2)	163·8	(o)
	1·762 (2)	99·0 (1)	117·4 (2)	145·7	
(iiib) : Azaphenoxathiin derivatives					
7-Chloro-1-azaphenoxathiin	1·759 (3)	100·8 (1)	123·2 (2)	175·7	(p)
8-Chloro-1-azaphenoxathiin	1·766 (2)	100·5 (1)	122·2 (2)	176·8	(p)
2-Azaphenoxathiin 2-oxide	1·758 (2)	99·1 (1)	120·0 (2)	160·8	(q)
	1·763 (2)	98·4 (1)	117·8 (1)	151·3	
9-Nitro-1-azaphenoxathiin	1·768 (7)	100·6 (3)	126·7 (6)	178·2	(o)
	1·756 (7)	101·2 (4)	123·1 (6)	177·1	

References: (a) Lynton & Cox (1956); Rowe & Post (1958). (b) Hosoya & Wood (1957). (c) Hosoya (1958a). (d) Hosoya (1958b). (e) Bell, Blount, Briscoe & Freeman (1968). (f) Chu & van der Helm (1974). (g) Chu & van der Helm (1975). (h) McDowell (1969). (i) McDowell (1970). (j) Phelps & Cordes (1974). (k) Marsau & Busetta (1973). (l) Marsau & Gauthier (1973). (m) Chu & van der Helm (1976). (n) Hosoya (1966). (o) Present report. (p) Martin, Korp, Turley & Bernal (1978). (q) Caldwell et al. (1981).

large number of such tricyclic compounds have been studied which broadly fall into three groups: (i) thianthrene and derivatives, (A = S, B = S); (ii) phenothiazine and derivatives (A = S, B = N); (iii) phenoxathiin and derivatives (A = S, B = O). Relevant geometrical features of some of these structures are given in Table 8, including the results of the present study.

The results in Table 8 indicate that in general Hosoya's assumption is correct in that most S-containing molecules are folded about the central S–X vector. However, there are several points of considerable interest. The variation of dihedral angles is quite noticeable. Not only do angles vary among the three general groups cited above but also within the individual groups as well. In some cases, folding about the central S–X vector within the individual groups varies dramatically with differences of as much as 40° or more in the dihedral angles.

Of the three parent compounds, thianthrene has the smallest dihedral angle (128°), phenothiazine the largest (153°) and phenoxathiin an intermediate value (138°). In the thianthrene derivatives, substitution at S seems to have little effect on the folding of the molecule. The average dihedral angle of the four compounds in this group is 125°, which is only slightly different from the value of their parent compound. In phenothiazine derivatives, the effect of substitution on the folding angle of the tricyclic nucleus is quite apparent. In general, substitution on N or on the aromatic rings seems to reduce the dihedral angle (increase the folding). The only exception is 2-methoxypromazine (157·4°) where the dihedral angle is increased by about 4° on substitution. The average dihedral angle of 11 molecules of different phenothiazine derivatives is 142·4°, which is about 11° smaller than that of the parent molecule. That the dihedral angle of the phenothiazine backbone is sensitive to the electronic nature of its substituents can be seen in the change of dihedral angle in going from chlorpromazine (139·4°) to 2-methoxypromazine (157·4°). Phenoxathiin, which has a smaller dihedral angle (138·4°), is spatially quite similar to the group of active phenothiazine derivatives. The structure of 1-nitrophenoxathiin (present report) is the first phenoxathiin derivative structure available. The effect of nitro substitution on the aromatic ring is manifested in the increase of the dihedral angle by 7·3 and 25·4°, respectively, in the two independent molecules. In molecule A, the nitro group is nearly coplanar with the benzene ring, while in molecule B it is rotated out of the plane of the benzene ring. It is probable that in the more folded conformation, the nitro groups rotate to minimize the energy of their interaction with the S atom.

The last four molecules in Table 8 are characterized by having an annular 'aza substitution', which is equivalent to replacing a benzene ring in phenoxathiin

by a pyridine ring. The effect of such a substitution is distinctly noticeable. In all three 1-aza-substituted compounds, 7-chloro-1-azaphenoxathiin (dihedral angle 175·7°), 8-chloro-1-azaphenoxathiin (176·8°), and 9-nitro-1-azaphenoxathiin (178·2 and 177·1°), the molecules are essentially planar, in spite of the fact that they have different substitution patterns. The 1-aza substitution, therefore, seems primarily responsible for the increased dihedral angle (decreased folding) in the tricyclic backbone rather than the substituents on the benzene ring. However, the positioning of the aza substitution seems to be critical as is evidenced by the results for 2-azaphenoxathiin 2-oxide (Caldwell *et al.*, 1981). This molecule is definitely non-planar (dihedral angles are 160·8 and 151·3° for the two independent molecules). Another indication of the importance of the positioning of the aza substituent has been pointed out by Martin, Korp, Turley & Bernal (1978). They compare the dihedral angles of 10-methyl-2,3-diazaphenothiazine (146·4°) with those of its analog, 3,4-dihydro-4-oxo-2,3-diazaphenothiazine (175·6°) (Andreetti, Bocelli & Sgarabotto, 1974*a,b*), and argue that in the latter compound the oxo substituent electronically approximates a ring N in the 1-position, and is in that way responsible for the opening of the dihedral angle. The present study provides some strong evidence in support of the suggestion that 1-aza substitution leads to a planar molecule.

It can be seen in Table 8 that the C—S—C angle varies between 97 and 101° for folded molecules to near-planar ones. The variation is so small that it can be assumed that the 'natural' valency angle of the S atom is still retained in near-planar molecules. Therefore, in such cases, Hosoya's (1963) assumption that the folding of S-containing tricyclic systems is a result of a hybridization change of the S atom is not necessarily valid. However, it is seen that the molecule with the larger dihedral angle has, in general, larger endocyclic angles in the central ring.

In 1-nitrophenoxathiin the difference in dihedral angle in the two molecules is quite large, 18°. Conformational differences for two crystallographically independent molecules are encountered relatively frequently in similar tricyclic compounds. There is a difference of 9·5° in 2-azaphenoxathiin 2-oxide (Caldwell *et al.*, 1981), 6·6° in triflupromazine (Phelps & Cordes, 1974) and 10·7° in *N*-isopropylphenothiazine (Chu & van der Helm, 1976). These results indicate that even in the absence of substituent effects, the phenothiazines and phenoxathiins have one broad, or more than one shallow, minimum-energy conformation, except in the cases where the molecules are essentially planar.

S⋯O interaction: The S⋯O(1) distances of 2·590 and 2·570 Å in the 9-nitro-1-azaphenoxathiin structure are significantly shorter than the sum of the van der Waals radii for S and O atoms, 3·15–3·25 Å.

Partial bonding or non-bonding interactions in similar compounds have been reported by Hamilton & LaPlaca (1964), Hordvik, Sletten & Sletten (1969), Reid & Paul (1971) and Beer, McMonagle, Siddiqui, Hordvik & Jynge (1979). This interaction appears to have strict geometric requirements, and is most likely a result of a balance of attractive (O lone-pair–empty S d orbitals) and repulsive (O lone-pair–S lone-pair) inter-actions. However, the S$\cdots$O distances in the present structure are much longer than the 2·44 Å observed in methyl O-nitrobenzenesulfenate (Hamilton & LaPlaca, 1964) or 2·373 Å observed in 2,4-epidithio-1-nitro-1-nitroso-4-phenylbutadiene (Reid & Paul, 1971). However, as in the sulfenate structure, the O(1)–S–C(1a) configuration in 9-nitro-1-azaphenoxathiin is approximately linear (176 and 177°), a favorable situation for an interaction. Even so, the linearity of these bonds may simply be a coincidental consequence of the preferred planarity and the normal bond lengths of the atoms involved.

In 1-nitrophenoxathiin, the S$\cdots$O distance of 2·606 Å and an O(1)–S–C(9a) angle of 170·3° along with the nearly planar five-membered ring [S, C(10a), C(1), N and O(1)] in molecule A still create a situation favorable for a weak S$\cdots$O interaction. But in the case of molecule B, the nitro group is rotated too far out of the plane leading to an O(1)–S–C(9a) angle of 163·6° and a non-planar five-membered ring (torsion angles in Table 6). Although the S$\cdots$O distance of 2·687 Å is much shorter than the sum of the van der Waals radii, the geometry is not nearly as favorable for an S$\cdots$O interaction.

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