Molecular Solute Conformation of Di-2-pyridyl Disulphide from Dipole Moment Studies

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The electric dipole moments of di-2-pyridyl and di-4-pyridyl disulphide have been measured in benzene solution at 25°. Conformational analysis carried out by vector addition has shown that free rotation about each C–S bond is allowed in the title compound.

THE problem of preferred conformations about the C–S bond in diphenyl disulphides has been recently discussed in some detail on the basis of dipole moment studies.[1] It was of interest to extend this investigation to analogous systems in which the C atom of the C–S bond is part of a pyridine ring. These compounds have not yet been investigated from a conformational aspect, in spite of their considerable interest both as inhibitors of biological processes[2] and as complexing agents for transition metals.[3]

This paper reports, together with dipole moment data for benzene solutions of di-2-pyridyl and di-4-pyridyl disulphide, analysis of the 2-isomer in terms of molecular solute conformation.

EXPERIMENTAL

Di-2-pyridyl disulphide, m.p. 57—58° (lit.,[4] m.p. 57°), and the 4-isomer, m.p. 76—77° (lit.,[4] m.p. 77°), were commercial products (Aldrich), purified by several recrystallizations to constant m.p. and $\varepsilon_{\max}$.

The electric dipole moments were determined at 25° ± 0·01 for benzene solutions using the apparatus, techniques of measurement, solvent constants, and method of assessment of purity of the samples described in detail elsewhere.[5] The dipole moments were evaluated by the Halverstadt–Kumler[6] and Guggenheim[7] methods. Both procedures gave the same values.

The probable error in μ has been estimated to be ±0·01 D for di-2-pyridyl disulphide and ±0·02 D for the 4-isomer.

RESULTS AND DISCUSSION

The results are given in the Table.

On the basis of previous dipole moment studies on model diphenyl disulphide systems[5,8] we consider that in di-2-pyridyl and di-4-pyridyl disulphide the C–S–S–C group exists in a rigid non-planar conformation with a dihedral angle of *ca.* 90° between the planes of the two C–S bonds.†

Rotational configurations about C–S bonds cannot be detected by electric dipole moment data in di-4-pyridyl disulphide, the resultant group moments in this molecule being collinear with the C–S axes. However, the resultant molecular dipole moment of the 2-isomer can be calculated by vector addition as a function of the rotation angles about the C–S bonds. The following assumptions have been made in the calculations. (i) The group moments μ_{PhS} = 1·29 D[8] and μ_{py} = 2·20 D[9] have been used. (ii) The angles given for diphenyl disulphide from *X*-ray diffraction data[10] are valid for di-2-pyridyl disulphide: the dihedral angle between the C–S bonds (Φ) is 96°, the $\widehat{\mathrm{CSS}}$ angle (θ) is 106°. (iii) A contribution of 0·57 D for the mesomeric moment is included in the vector analysis.

Total polarizations, molar refractions, and dipole moments and other parameters for their evaluation

	α	ε_{10}	β	v_{10}	$P_{2\infty}$/cm³	R_D/cm³	μ/D
Di-2-pyridyl disulphide	8·32	2·2719	−0·360	1·14311	395·83	66·61	3·99
Di-4-pyridyl disulphide	1·62	2·2710	−0·341	1·14307	119·68	66·61	1·90

$\alpha = \mathrm{d}\varepsilon_{12}/\mathrm{d}w_2$; $\beta = \mathrm{d}v_{12}/\mathrm{d}w_2$; $\varepsilon_{10} = \lim_{w_2\to 0} \varepsilon_{12}$; $v_{10} = \lim_{w_2\to 0} v_{12}$.

Assumption (iii) has been made on the basis of a precise estimate of the mesomeric moment in di-4-pyridyl disulphide. For this molecule the apparent group moment μ_{pyS} can be evaluated from the experimental dipole moment (1·90 D) *via* the relation (1)

$$\mu_{\mathrm{exp}} = 2\mu_{\mathrm{pyS}} \sin\theta \cos\Phi/2 \qquad (1)$$

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† As a check we measured the electric dipole moments of di-2-pyridyl and di-4-pyridyl disulphide at 45°. The constancy of the moment with change in temperature found in both compounds provided further evidence that free rotation about the S–S bond is highly hindered. On the same basis the possibility that the molecule of di-2-pyridyl disulphide exists in an average conformation in which the rings oscillate about the C–S bonds can be excluded. Calculations have shown that the increase in the amplitude of oscillation which should accompany the rise of temperature should give rise to an average dipole moment very different from the 3·99 D found at 25°.

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where the angles Φ and θ have the values of assumption (ii). From the difference between the value of 1·48 D given by (1) and the calculated (0·91 D) by vector sum (2) for the pyS portion, a value of 0·57 D has been

$$\mu^2_{\mathrm{pyS}} = \mu^2_{\mathrm{py}} + \mu^2_{\mathrm{PhS}} + 2\mu_{\mathrm{py}}\mu_{\mathrm{PhS}} \cos 180° \qquad (2)$$

determined for the magnitude of the mesomeric moment of di-4-pyridyl disulphide. Now it is reasonable to consider that mesomeric interaction changes slightly on going from di-4-pyridyl to di-2-pyridyl disulphide. Therefore we use in the calculations for this molecule the group moments together with a mesomeric moment of 0·57 D for the conjugation of the S atoms with the pyridine nuclei.*

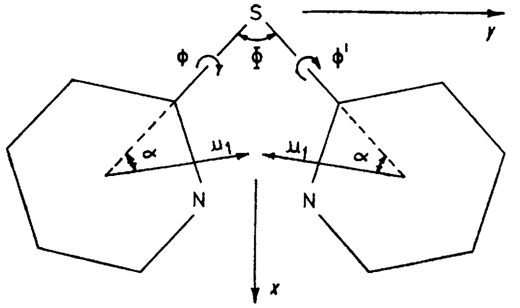

FIGURE 1 Di-2-pyridyl disulphide oriented along the co-ordinate system of axes as viewed along the *z*-axis. The conformation in which ϕ = 180, ϕ' = 0 is shown

The vector analysis was then carried out by orienting the molecule of di-2-pyridyl disulphide in a system of co-ordinates as shown in Figure 1. The *x*-axis is taken as bisecting the dihedral angle Φ, the *y*-axis is the external tangent to this angle, and the *z*-axis is coincident with the S–S linkage. The possible rotational conformations of the molecule are defined by the rotation angles ϕ and ϕ' described in the clockwise direction. Both angles are taken as zero when the molecule is in the conformation in which each C–S–S plane is orthogonal to each pyridine ring plane and the N atoms are oriented one inside and the dihedral angle between the C–S one outside bonds (see Figure 1). By reference to this model the resultant molecular dipole moment can be calculated according to relation (3) in which the com-

$$\mu = [(\mu^2_x + \mu^2_y + \mu^2_z)]^{\frac{1}{2}} \qquad (3)$$

ponent moments along each co-ordinate axis are given by equations (4)—(6) where $\alpha = 37{\cdot}5°$. This angle has been

$$\mu_x = (\mu_{\mathrm{PhS}} \sin \alpha) \cos \phi' \sin \Phi/2 - 2(\mu_{\mathrm{py}} \cos \alpha) \cos \Phi/2 \cos (\theta - 90°) - (\mu_{\mathrm{PhS}} \sin \alpha) \cos \phi \sin\Phi/2 \qquad (4)$$

$$\mu_y = \mu_{\mathrm{PhS}} \sin \alpha \cos \Phi/2\ (\cos \phi' - \cos \phi) \qquad (5)$$

$$\mu_z = [\mu_{\mathrm{PhS}} \sin \alpha \cos (\theta - 90°)](\sin \phi - \sin \phi') \qquad (6)$$

estimated from expression (7) in which the resultant vector μ_1 is given by (8).

$$\sin \alpha = (\mu_{\mathrm{py}} \sin 120°)/\mu_1 \qquad (7)$$

$$\mu_1{}^2 = \mu^2_{\mathrm{py}} + \mu^2_{\mathrm{PhS}} - 2\mu_{\mathrm{py}}\mu_{\mathrm{PhS}} \cos 120° \qquad (8)$$

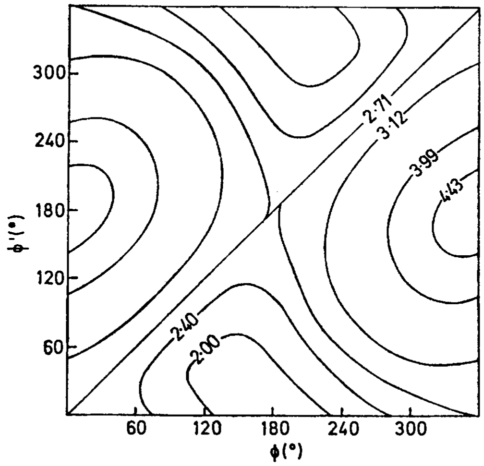

FIGURE 2 Contour map of the calculated dipole moment of di-2-pyridyl disulphide as a function of the rotation angles about the C–S bonds

Results of the calculations are shown by the contour map (Figure 2) in which computed moments are plotted as function of the rotation angles ϕ and ϕ'. The contour 3·99 connects all points for which $\mu_{\mathrm{calc}} = \mu_{\mathrm{exp}}$. However, examination of this contour allow us to exclude the conformations given by the values of ϕ and ϕ' at which calculated and experimental dipole moments of di-2-pyridyl disulphide agree, since it is obvious that unsymmetrical forms with different conformations for equivalent bonds in both halves of the molecule are very unlikely.

It can be also seen that the points on the diagonal of the graph correspond to conformations which can be obtained by concerted rotation (*i.e.* about ϕ and ϕ') of the pyridine groups about the C–S axes starting from the above stated molecular model (*cf.* Figure 1). The calculated dipole moment for any of these possible unsymmetrical conformations is 2·71 D, which is in poor agreement with the experimental value.

Moreover, is of interest to observe that on the basis of the large difference between μ_{exp} and μ_{calc} we can exclude the two conformations in which both pyridine groups lie on the C–S–S plane, the N atoms being *trans–trans* (ϕ = 170 ϕ' = 90°) or *cis–cis* (ϕ = 90 ϕ' = 270°) to the S–S group. This latter conformation is the one which might be expected as favoured on the basis of the conclusions of Lumbroso and Bertin [11] for the molecule of methyl 2-pyridyl sulphide. Their work in fact suggested that this molecule exists principally in a planar conformation in which the N atom is *cis* to the methylthio-group.

Therefore, by excluding any fixed conformation, the possibility of free rotation of the pyridine groups

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* This correction, although small, must be included in the vector analysis since computations have shown that the condition $\mu_{\mathrm{exp}} > \mu_{\mathrm{calc}}$ would be verified by all possible structures if we assume $\mu_m = 0$. The inclusion has been made by distributing equally the contribution of 0·57 D among the assumed group moments.

[11] H. Lumbroso and D. M. Bertin, *Bull. Soc. chim. France*, 1970, 1728.

about the C–S bonds must be taken in account for di-2-pyridyl disulphide.

It is clear that the possibility of free rotation about C–S bonds implies a weakened π-electron interaction of each S atom with its attached pyridine ring. Because of this reduced mesomeric effect we may reasonably consider that interaction changes the individual moments to a negligible extent and thus we assume in the calculations $\mu_m = 0$.

Assumptions (i) and (ii) made above are valid. For the particular case of di-2-pyridyl disulphide, application of the Eyring's formula[12] to the free rotation of the resulting moment μ_1 about each C–S bond gives equation (9) where α and μ_1 are given by (7) and (8),

$$\mu^2 = 2\mu_1^2 + 2\mu_1^2 \cos^2 \alpha \cos \omega \qquad (9)$$

and ω is the angle which the directions of the axes of rotation form with one another. It then follows from simple geometry that this angle can be expressed by (10)

$$\omega = 2 \arcsin [(\cos^2 (\theta - 90°) \sin^2\Phi/2 + \sin^2 (\theta - 90°)]^{\frac{1}{2}} \qquad (10)$$

from which we obtain $\omega = 99{\cdot}9°$.

The computations give a calculated dipole moment (4·08 D) which is close to the experimental one of 3·99 D, thus providing strong evidence for free rotation of the pyridine groups about the C–S bonds. The small discrepancy of 0·09 D between μ_{calc} and μ_{exp} could arise from altered component moments caused by inductive effects of the S and N atoms on the C atom bonded to them.

The same possibility of free rotation about C–S bonds can be postulated for di-4-pyridyl disulphide, although the higher value of the interaction moment suggests that small overlap between the sulphur *p* orbital and the 2*p* orbitals of the π system can occur in this molecule.

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