Rotational Isomerism in *N*-(*N*-Heteroaryl)arenesulphenamides

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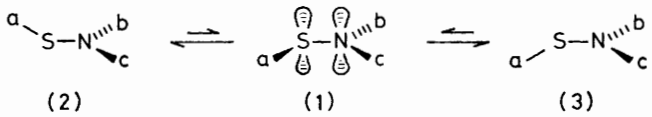
N-(1,2-Dihydro-2-oxoquinolin-1-yl)-*N*-(1-methylallyl)-4-chlorobenzenesulphenamide (5) has previously been isolated in two stereoisomeric forms. From examination of a number of analogues of (5), it is concluded that the phenomenon which allows isolation of these stereoisomers is restricted rotation around the N–N bond.

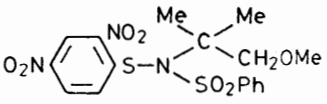
THE work of Raban and his co-workers has established that a substantial barrier can exist to rotation (torsion) about the S–N bond.[1] This barrier may be represented by the planar conformation (1) (Scheme 1) † where the



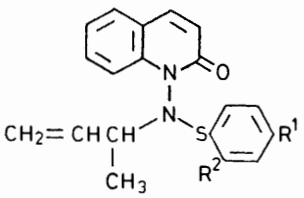
(2) (1) (3)

SCHEME 1

repulsive interaction between lone pairs on nitrogen and sulphur is at a maximum. The S–N bond in sulphenamides is a chiral axis: (2) and (3) are related as mirror images with racemisation occurring *via* (1). The presence of this chiral axis can be detected using n.m.r. spectroscopy by employing prochiral substituents on nitrogen (or sulphur), usually benzyl or isopropyl groups in which the diastereoisotopic protons or methyl groups have different chemical shifts. Rapid rotation around the S–N bond on the n.m.r. time-scale will remove this chemical shift difference and at the coalescence temperature, the energy barrier to S–N bond rotation can be calculated. It has been found that the barriers so calculated are highest with electron-withdrawing groups on sulphur; for example, that for the sulphenamide (4) has a value of 21.4 kcal mol^{-1}.[2]



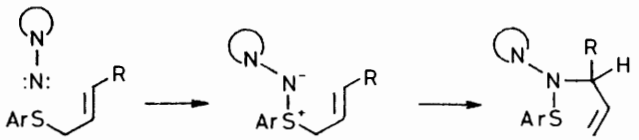
(4)



(5) R^1 = Cl, R^2 = H
(15) R^1 = H, R^2 = NO_2
(16) R^1 = R^2 = NO_2

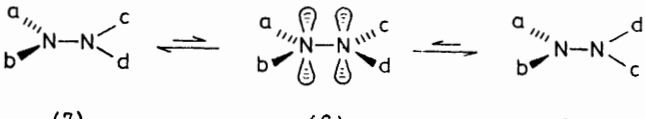
We became interested in sulphenamide rotation barriers as a result of studying the addition of *N*-nitrenes to substituted allyl aryl sulphides.[3] The resulting sulphenamides, presumably formed by [2,3] sigmatropic rearrangement of intermediate sulphimides (Scheme 2), showed unexpected temperature dependent features in their n.m.r. spectra.

Thus, the product from oxidation of *N*-aminoquinolone in the presence of *p*-chlorophenyl crotyl sulphide was the sulphenamide (5) whose n.m.r. spectrum shows two methyl doublets (δ 0.93 and 1.48 in $CFCl_3$) of unequal intensity. By a combination of crystallisation and chromatography we have separated the two stereoisomers responsible for these signals and have carried out *X*-ray structure determinations on both of them.[4] It is evident from the *X*-ray structures that the sulphenamide nitrogen in both stereoisomers is pyramidal and hence there are three possible contenders for the additional chirality in (5), besides that at C-1, which



SCHEME 2

could account for the existence of stereoisomers: (a) absence of inversion at the sulphenamide nitrogen, (b) restricted rotation around the S–N bond, or (c) restricted rotation around the N–N bond. If condition (c) obtained, the N–N bond would become a chiral axis since the preferred conformation adopted [(7) or (8), Scheme 3]



(7) (6) (8)

SCHEME 3

is that in which repulsion between lone pairs (and substituents) is minimised.[5] In a situation very similar to that in Scheme 1, (7) and (8) are mirror images provided that a ≠ b and c ≠ d ‡ with racemisation occurring *via* (6).

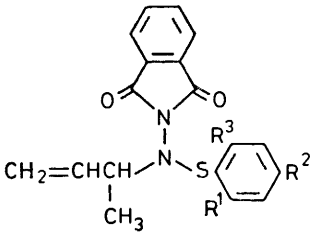
Unfortunately, the *X*-ray structures of the two stereoisomers do not allow a choice to be made among (a)—(c). In this paper we present evidence which supports (c), restricted rotation around the N–N bond, as being the factor allowing isolation of stereoisomers in the case of (5).[6] Some support for this conclusion was already available from the n.m.r. spectrum of (9), the phthalimido analogue of (5), in which only a single methyl doublet is observed at all temperatures and in all solvents examined.[3] The symmetry of the phthalimido group (a = b; Scheme 3) means that the N–N bond is no longer a chiral axis.

We have examined sulphenamides of type (9) (in

† For simplicity here the nitrogen atom is assumed to be sp^2-hybridised.

‡ Again for simplicity here both nitrogens are assumed to be planar.

which complications from an N–N chiral axis are removed) in more detail and have synthesised the mono- and bis-nitrophenyl analogues (10) and (11). In the n.m.r. spectrum of (11) at 220 MHz and 0 °C, the methyl group appears as a pair of doublets [δ 1.36 and 1.42 (*J* 6.5 Hz) in the ratio 1 : 1.4]. The presence of stereoisomers is also apparent in the resonances of the dinitrophenyl ring and, in particular, the proton *ortho* to

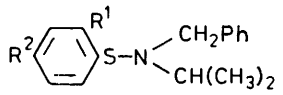


(9) $R^1 = R^3 = H, R^2 = Cl$
(10) $R^1 = NO_2, R^2 = R^3 = H$
(11) $R^1 = R^2 = NO_2, R^3 = H$
(14) $R^1 = R^2 = R^3 = NO_2$

sulphur for which two doublets are also observed [δ 9.28 and 9.35 (*J* 9.5 Hz) in the ratio 1 : 1.4]. Coalescence of the latter pair of doublets and those of the methyl groups is observed at 39 °C indicating an associated barrier $\Delta G^{\ddagger}$ of 16.8 kcal mol^{-1}.[7] Similarly, stereoisomers were also visible in the n.m.r. spectrum of (10) with the barrier in this case falling to 14.6 kcal mol^{-1} as calculated from coalescence of methyl doublets at δ 1.36 and 1.31.

The magnitudes of the barriers calculated for (10) and (11) are remarkably close to those in (12) and (13) (16.9 and 14.9 kcal mol^{-1}, respectively) and assignable to torsion around the S–N bond.[8,*] Measured energy barriers to rotation around S–N bonds in (10)—(13) and related compounds are given in the Table.

We also attempted the preparation of the trinitrophenyl analogue (14) since it has been shown that whereas introduction of one and two nitro groups progressively raises the S–N torsion barrier in arenesulphenamides, a



(12) $R^1 = R^2 = NO_2$
(13) $R^1 = NO_2, R^2 = H$

third nitro group reduces it.[2] Unfortunately the *N*-nitrenes we employed do not appear to react with crotyl picryl sulphides to give sulphenamides.

A more complicated picture emerged from a study of (15) and (16), the mono- and bis-nitrophenyl analogues of the quinolone-substituted sulphenamide (5). Thus in the n.m.r. spectrum of (16), four methyl doublets (δ 1.18, 1.32, 1.50, and 1.60 in the ratio 7.3 : 1 : 2 : 4.5) are observed at 220 MHz and −40 °C. Two chiral axes (S–N and N–N) and the chiral centre at C-1 give rise to four possible diastereoisomers which are presumably responsible for these signals. In the n.m.r. spectra of (10), (11), and (16) the proton *ortho* to sulphur appears at abnormally low field: we ascribe this deshielding to the carbonyl groups of the phthalimide or quinolone rings (or the aromatic ring of the latter).

The energy barrier which has allowed us to separate stereoisomers in the case of (5) and, more recently, (15) is evidently grossly different from that responsible for the coalescence of methyl doublets in the n.m.r. spectra of (10) and (11). Significantly also, coalescence of only two pairs of the four methyl doublets in the n.m.r. spectrum of (16) is observed over a broad range at 0 °C corresponding, we presume, to S–N bond rotation becoming fast on the n.m.r. time-scale. Substitution of a quinolone for a phthalimide ring, therefore, does not dramatically affect the S–N torsion barrier.

Free energies of activation for rotation about S–N and N–N bonds evaluated from n.m.r. data

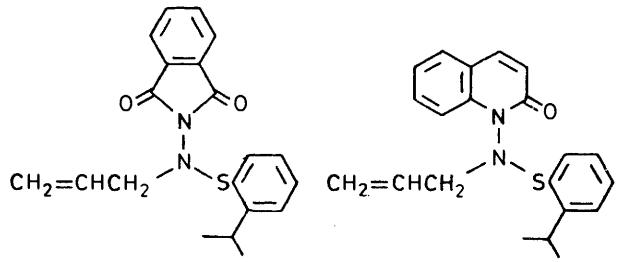
Compd.	T_c [a]	$\Delta\nu$ [b]	$W_{\frac{1}{2}}$ [c]	J_{AB} [b]	k_c [b]	$\Delta G^{\ddagger}$ [d]	
(10) [e]	−2 [f]	4.5				14.6 [g]	Retarded S–N bond rotation
	2 [h]	6.5				14.6 [g]	
(11) [e]	39 [f]	5.0				16.8 [g]	
	43 [h]	6.5				16.8 [g]	
(12) [e]	26 [i]		8.0	13.6	72.5	14.9 [j]	
(13) [e]	66 [i]		9.0	13.9	77	16.9 [j]	
(25) [k]	~28 [l]		19.0	12.5	89	14.9 [j]	
(23) [e]	~32 [f]	36				15.2 [g]	
		E_a [d]		$\Delta S^{\ddagger}$ [m]			Retarded N–N bond rotation
(5) [n]		28.6 ± 0.6 [o]		5.0 ± 1.8		26.1	
(15) [n]		25.5 ± 0.7 [p]		−1.3 ± 2.3		25.3	

[a] °C. [b] Hz. [c] Width (Hz) at half-height at T_c. [d] kcal mol^{-1}. [e] Measured at 100 MHz in $CDCl_3$. [f] Using methyl doublets at C-1. [g] Evaluated using k_c 2.22 $\Delta\nu$ and the Eyring equation. [h] Using the aromatic H-6. [i] Using coalescence of benzyl CH_2 from AB system to singlet. [j] Evaluated using the method of Kost *et al.*[7] [k] Measured at 100 MHz in $C_6D_5CD_3$. [l] Using coalescence of allyl CH_2 and assuming coalescence in ABX system can be treated as in AB system. [m] cal K^{-1} mol^{-1}. [n] In chlorobenzene at 100 MHz. [o] Evaluated from four different temperatures. [p] Evaluated from three different temperatures.

To quantify the barrier separating the stereoisomers of (5), we have measured the first-order rate constants at different temperatures for conversion of the stereoisomer showing the higher field doublet [δ ($CFCl_3$) 0.93] in its n.m.r. spectrum, into the equilibrium mixture. From the resulting Arrhenius plot, the thermodynamic parameters in the Table are evaluated with $\Delta G^{\ddagger}$ 26.1 kcal mol^{-1}. Similarly the corresponding parameters (Table) for the *o*-nitrophenyl analogue (15) were obtained using the stereoisomer having the methyl doublet at δ 1.17 giving $\Delta G^{\ddagger}$ 25.3 kcal mol^{-1}. Since rotation around the N–N bond in sp^2–sp^3 hybridised hydrazines normally has an associated barrier $\Delta G^{\ddagger}$ of <18 kcal mol^{-1},[9] some explanation for the magnitude of the barriers in (5) and (15) is required if we are to attribute it to N–N bond rotation. In pursuit of such an explanation we have synthesised a number of analogues of (5) and examined their n.m.r. spectra at different temperatures.

* Inversion at the pyramidal nitrogen in this case is believed to be fast by comparison with the S–N bond rotation.

Reaction of *N*-aminophthalimide with allyl *o*-isopropylphenyl sulphide and lead tetra-acetate gave the expected sulphenamide (17) in which only one methyl doublet was observable for the isopropyl group. However, the corresponding sulphenamide (18) from a similar reaction using *N*-aminoquinolone showed two distinct methyl doublets for the now diastereoisotopic methyl groups of the isopropyl substituent; no coalescence of

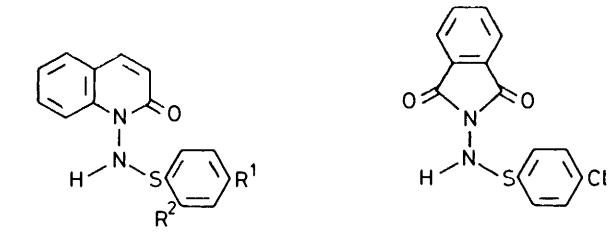


(17) (18)

these doublets was observed up to 100 °C. Presumably, it is again the N–N chiral axis in (18) which is responsible for the prochirality of isopropyl.

Sulphenylation of *N*-aminoquinolone and *N*-aminophthalimide with *p*-chlorophenylsulphenyl chloride and triethylamine gave sulphenamides (19) and (20). There is no prochiral probe in either of these compounds but the *o*-isopropyl analogue (21) again shows only a single doublet for the isopropyl methyl groups even at low temperatures (−50 °C at 100 MHz). It appears therefore, that the N–N rotational barrier is reduced considerably by comparison with (18) on replacing the *N*-alkyl substituent by hydrogen.

The 2,4-dinitrophenyl-substituted sulphenamide (22) was synthesised in the expectation that chiral S–N and



(19) $R^1 = Cl, R^2 = H$
(21) $R^1 = H, R^2 = CH(CH_3)_2$
(22) $R^1 = R^2 = NO_2$

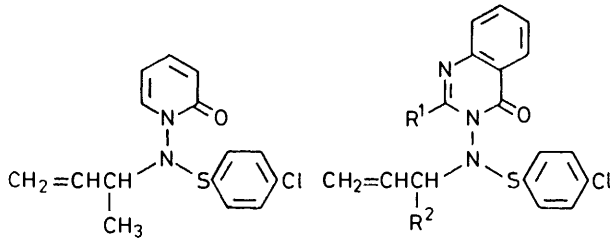
(20)

N–N axes would give rise to stereoisomers, perhaps differing in chemical shift of the protons of their 2,4-dinitrophenyl rings as in the case of (11). From an examination of the spectrum of (22), however, only a single compound appeared to be present.

Oxidation of *N*-aminopyridone in the presence of *p*-chlorophenyl crotyl sulphide gave the sulphenamide (23) whose n.m.r. spectrum proved to be very informative. Thus two methyl doublets are observed at −40 °C but coalescence occurs at *ca.* 32 °C; at still higher temperatures a single doublet is observed. Since the only difference between (23) and (5) is the additional benzene ring, the latter must account for the large increase in the rotational barrier around the N–N bond (Table). In particular, we suppose that it is steric interaction of the substituents on the sulphenamide nitrogen (sulphur, allyl, or α-methylallyl) and the *peri*-H at C-8 which is responsible. It appears that both the sulphur and the alkyl group on the sulphenamide nitrogen are unable to pass by the *peri*-H since if either is replaced by hydrogen, the extraordinarily high barrier disappears.

A similar inhibition to rotation around the N–N bond is also present in the quinazolone-substituted sulphenamide (24). As anticipated, this barrier is drastically lowered in the related (25), lacking methyl groups in both the quinazolone ring and allyl group.[10]

The lower barrier in the pyridone-sulphenamide (23)



(23) (24) $R^1 = R^2 = Me$ (25) $R^1 = R^2 = H$

relative to the quinolone analogue (5) also excludes (a), retarded inversion at the sulphenamide nitrogen, as the phenomenon allowing isolation of stereoisomers in (5) since an increase in size of the nitrogen substituents *lowers* the barrier to *N*-inversion.[11] It is possible that the process which brings about interconversion of the stereoisomers in (5) and (15) is not simple rotation around the N–N bond. Other processes, including homolysis–recombination could formally lead to the same result.

EXPERIMENTAL

M.p.s were determined with a Kofler hot stage apparatus and are uncorrected. I.r. spectra of crystalline compounds were determined using Nujol mulls and other compounds as thin films using a Perkin-Elmer 237 spectrometer. N.m.r. spectra were determined using a Varian T60 or JEOL PS–100 and ^{13}C spectra using a JEOL FX–60 Fourier-transform spectrometer; 220 MHz spectra were measured by courtesy of PCMU Harwell. Chemical shifts are expressed in p.p.m. relative to internal tetramethylsilane. Mass spectra were measured with a V.G. Micromass 16B instrument. Light petroleum refers to the fraction of b.p. 60—80° unless otherwise stated. Basic alumina is UGI (S. Lancaster and Co.) and Kieselgel is type PF_{254} (Merck).

The following compounds were prepared by literature methods: *N*-aminophthalimide,[12] 3-amino-4-quinazolone,[13] 3-amino-2-methyl-4-quinazolone,[14] 1-amino-2-quinolone,[14] allyl 4-chlorophenyl sulphide,[15] *trans*-but-2-enyl 4-chlorophenyl sulphide.[3] 2,4-Dinitrobenzenesulphenyl chloride was obtained commercially (Aldrich Chemical Co.).

trans-*But-2-enyl 2-Nitrophenyl Sulphide.*—A solution of sodium (1.05 g) in ethanol (40 ml) was prepared and 2-nitrobenzenethiol[16] (7 g) added. The mixture was stirred at 0 °C under nitrogen and 1-bromobut-2-ene (7 g) added

dropwise. After stirring overnight, ethanol was evaporated under reduced pressure, the mixture poured into water, and ether extracted. The extracts were dried (Na_2SO_4) and the ether removed leaving a brown oil which was distilled, b.p. 145—160° at 1 mmHg, giving a yellow oil (5.9 g, 63%) pure enough to be used in the preparation of the sulphenamides below. An analytical *sample* was obtained by low temperature crystallisation from ethanol, m.p. 25—26 °C (Found: C, 57.4; H, 5.35; N, 6.6. $C_{10}H_{11}NO_2S$ requires C, 57.4; H, 5.3; N, 6.7%); δ($CDCl_3$) 8.15 (d, *J* 8 Hz, ArH-3), 7.6—7.1 (m, 3 × ArH), 6.0—5.4 (m, 2 × olefinic H), 3.6 (d, further split, *J* 6 Hz, CH_2), and 1.7 (d, further split, *J* 6 Hz, CH_3); $\nu_{max.}$ 3 040w, 1 595s, 1 565s, 1 510s, 1 340s, 960s, and 740s cm^{-1}; *m/e* 209 (M^+), 179, 155, 139, 138, 125, 124, 91, and 55 (base).

2-*Isopropylbenzenethiol*.[17]—Benzenethiol (27.5 g) and anhydrous aluminium trichloride (5 g) were stirred under nitrogen in a three-necked flask (100 ml) fitted with two dry ice condensers. Propene (5.25 g) was added slowly *via* one dry ice condenser over 25 min, the mixture being cooled in an ice–salt-bath. After stirring for a further 20 min, benzene (40 ml) was added, then water (40 ml) (slowly at first). The organic layer was separated, washed with water and then extracted with sodium hydroxide solution (2 × 70 ml, 2M). The combined alkaline extracts were acidified with concentrated hydrochloric acid and re-extracted with ether (2 × 50 ml), the ether extract dried (Na_2SO_4), evaporated, and the residual oil distilled using a Vigreux column. After removal of the unchanged benzenethiol (11 g), b.p. 45—55° at 7 mmHg, 2-isopropylbenzenethiol was obtained (4.95 g, 13%), b.p. 80—100° at 7 mmHg.

Allyl 2-Isopropylphenyl Sulphide.—This was prepared from 2-isopropylbenzenethiol (5 g) and allyl chloride (3 g) using the literature method for the preparation of allyl 4-chlorophenyl sulphide.[15] The crude product (5.4 g, 85%) was distilled, b.p. 90—100° at 2 mmHg; δ($CDCl_3$) 7.5—7.0 (m, 4 × ArH), 6.2—5.6 (m, :CH), 5.4—4.9 (m, $:CH_2$), 3.5 [d, further split, *J* 7 Hz, CH_2S, superimposed on 3.5 [m, *J* 6.5 Hz, $CH(CH_3)_2$]}, and 1.2 (d, *J* 6.5 Hz, 2 × CH_3).

Reaction of Nitrenes with Allyl Aryl Sulphides; General Procedure.—An *N*-amino-compound (1 mol. equiv.) and the allyl aryl sulphide (1.2—1.5 mol. equiv.) were stirred in dichloromethane (10 ml per g *N*-amino-compound) and powdered lead tetra-acetate (1 mol. equiv.) was added portionwise over 15 min to the magnetically stirred solution. After a further 20 min, the mixture was filtered and the separated solids washed with dichloromethane. The filtrate was evaporated and the residue chromatographed over alumina using 9 : 1 light petroleum–ethyl acetate. Unchanged allyl aryl sulphide was eluted first and further elution with 1 : 1 light petroleum–ethyl acetate yielded the sulphenamides. The following sulphenamides were prepared in this way: N-*allyl*-N-*phthalimido*-2-*isopropylbenzenesulphenamide* (17) (30%) from *N*-aminophthalimide and allyl 2-isopropylphenyl sulphide, crystals (from light petroleum), m.p. 93.5—95 °C (Found: C, 67.9; H, 5.8; N, 8.0. $C_{20}H_{20}N_2O_2S$ requires C, 68.2; H, 5.7; N, 7.95%); δ($CDCl_3$) 8.26 (dd, *J* 7, 2 Hz, ArH-6), 7.85—7.55 (m, 4 × phthalimido H), 7.4—7.1 (m, 3 × ArH), 6.2—5.8 (m, :CH), 5.3—5.0 (m, $:CH_2$), 4.20 (d, *J* 7 Hz, CH_2N), 2.98 [heptet, *J* 6.5 Hz, $CH(CH_3)_2$], and 1.18 (d, *J* 6.5 Hz, 2 × CH_3); $\nu_{max.}$ 3 070w, 1 790w, 1 730s, 885s, 795s, 760s, and 720s cm^{-1}; N-*allyl*-N-(1,2-*dihydro*-2-*oxoquinolin*-1-*yl*)-2-*isopropylbenzenesulphenamide* (18) (36%), from 1-amino-2-quinolone and allyl 2-isopropylphenyl sulphide, crystals [from light petroleum (b.p. 40—60 °C)], m.p. 60—61.5 °C (Found: C, 71.9; H, 6.3; N, 8.0. $C_{21}H_{21}N_2OS$ requires C, 72.0; H, 6.3; N, 8.0%); δ($C_6D_5CD_3$) 8.0—7.65 and 7.30—6.75 (m, 8 × ArH + quinoline H-4), 6.55 (d, *J* 9.5 Hz, quinoline H-3), 6.1—5.6 (m, :CH), 5.20—4.25 (structured *m*, NCH_2 and $:CH_2$), 3.40 [m, *J* 7 Hz, $CH(CH_3)_2$], and 1.02 and 0.82 (d, *J* 7 Hz, 2 × CH_3), the spectrum was essentially unchanged at 27 and 100 °C in $C_6D_5CD_3$; $\nu_{max.}$ 3 075w, 1 670s, 1 600s, 820s, 755s, and 740s cm^{-1}; N-(1,2-*dihydro*-2-*oxoquinolin*-1-*yl*)-N-(1-*methylallyl*)-2-*nitrobenzenesulphenamide* (15) (59%), from 1-aminoquinol-2-one and *trans*-but-2-enyl 2-nitrophenyl sulphide, lemon crystals (from ethanol), m.p. 143—143.5 °C (Found: C, 62.1; H, 4.7; N, 11.4. $C_{19}H_{17}N_3O_3S$ requires C, 62.1; H, 4.7; N, 11.4%); δ($CDCl_3$) 8.72 and 8.20 (2 × d, *J* 8 Hz, benzene H-6 and -3), 8.05—7.05 (m, 6 × ArH + quinoline H-4), 6.70 (d, *J* 9.5 Hz, quinoline H-3), 6.4—6.0 (m, :CH), 5.5—5.1 (m, $:CH_2$), 5.1—4.8 (m, NC*H*), and 1.55 and 1.17 (2 × d, *J* 7 Hz, 2 × CH_3): two diastereoisomers are indicated by the duplicated methyl peaks at δ 1.55 and 1.17 whose ratio in the crude mixture was 1 : 3. Repeated crystallisation from acetonitrile gave the predominant stereoisomer (δ 1.17), m.p. 141—142 °C. After heating for 1 h at 80 °C, the ratio of stereoisomers changed from 1 : 3 to 3 : 2, $\nu_{max.}$ 1 650s, 1 592s, 1 560s, 1 505s, 1 335s, 825s, and 725 sm^{-1}.

N-(1,2-*Dihydro*-2-*oxoquinolin*-1-*yl*)-N-(1-*methylallyl*)-2,4-*dinitrobenzenesulphenamide* (16). This was formed (18%) from 1-aminoquinol-2-one and *trans*-but-2-enyl 2,4-dinitrophenyl sulphide[18] as yellow crystals (from ethanol–acetonitrile), m.p. 162—163 °C (Found: C, 55.2; H, 4.2; N, 13.5. $C_{19}H_{16}N_4O_5S$ requires C, 55.3; H, 3.9; N, 13.6%); δ($CDCl_3$; 51 °C) 9.20 (d, *J* 9 Hz, benzene H-6), 9.00 (d, *J* 2 Hz, benzene H-3), 8.50 (dd, *J* 2, 9 Hz, benzene H-5), 8.0—7.2 (m, 4 × ArH + quinoline H-4), 6.70 and 6.68 (2 × d, *J* 9.5 Hz, quinoline H-3), 6.4—5.7 (m, :CH), 5.5—4.8 (structured m, NCH and $:CH_2$), and 1.50 and 1.27 (2 × d, *J* 7 Hz, 2 × CH_3): two diastereoisomers evident as in (15) above. At −40 °C and 220 MHz four methyl doublets were observed at δ 1.60, 1.50, 1.32, and 1.18 (ratio 4.3 : 2 : 1 : 7.3) as a result of slow N–N and S–N bond rotation on the n.m.r. time-scale. Coalescence of these four doublets into the two above at δ 1.50 and 1.27 occurs over a broad range between −18 and +9 °C; $\nu_{max.}$ 1 660s, 1 590s, 1 560m, 1 510s, 1 340s, 830m, 750s, and 730s cm^{-1}.

N-(1,2-*Dihydro*-2-*oxopyridin*-1-*yl*)-N-(1-*methylallyl*)-4-*chlorobenzenesulphenamide* (23). This was formed (47%) from 1-aminopyridin-2-one and *trans*-but-2-enyl 4-chlorophenyl sulphide as crystals (from light petroleum), m.p. 84—86 °C (Found: C, 58.9; H, 5.0; N, 9.1. $C_{15}H_{15}ClN_2OS$ requires C, 58.7; H, 4.9; N, 9.1%); δ($CDCl_3$; −40 °C) 7.35br (s, 7 × ArH), 6.64 and 6.58 (2 × d, *J* 9.5 Hz, 2 × pyridine H-3), 6.05—4.4 (structured m, $NCHCH{=}CH_2$), and 1.41 and 1.05 (2 × d, *J* 6.5 Hz, 2 × CH_3). Coalescence of the doublets at δ 1.41 and 1.05 (ratio 2 : 1) occurs at 30—35 °C (coalescence of other signals is also observed) and at 101 °C a singlet doublet is present, δ(PhCl) 1.29; $\nu_{max.}$ 3 070w, 1 660s, 1 590s, 1 535m, 930w, and 765w cm^{-1}. The 1-aminopyridin-2-one used above was conveniently prepared by amination of 2-pyridone using hydroxylamine-*O*-sulphonic acid as described for 2-quinolone.[14] Crystallisation of the product from light petroleum–ethyl acetate gave material (8%), m.p. 63—65 °C (lit.,[19] 64—66 °C).

N-*Allyl*-N-(3,4-*dihydro*-4-*oxoquinazolin*-3-*yl*)-4-*chlorobenzenesulphenamide* (25). This was formed (29%) from 3-aminoquinazol-4-one and allyl 4-chlorophenyl sulphide as

crystals (from ethanol), m.p. 85—86 °C (Found: C, 59.3; H, 4.1; N, 12.3. $C_{17}H_{14}ClN_3OS$ requires C, 59.4; H, 4.1; N, 12.2%); $\nu_{max.}$ 3 060w, 1 680s, 1 600s, 875s, 805s, 770s, and 690s cm^{-1}; $\delta(C_6D_5CD_3)$ 8.25 (d, *J* 7 Hz, quinazolone H-5), 7.85 (s, quinazolone H-2), 7.55 (d, *J* 8 Hz, quinazolone H-8), 7.36—6.8 (m, 6 × ArH), 5.8—5.4 (m, :CH), 5.0—4.75 (m, :CH_2), and 4.15br (s, NCH_2). The signal at δ 4.15 sharpens to a doublet at +50 °C (*J* 7 Hz) but at −42 °C becomes an ABX system (*J* 7 × 12.5 Hz).

N-(3,4-*Dihydro*-2-*methyl*-4-*oxoquinazolin*-3-*yl*)-N-(1-*methylallyl*)-4-*chlorobenzenesulphenamide* (24). This was formed (60%) from 3-amino-2-methylquinazol-4-one and *trans*-but-2-enyl 4-chlorophenyl sulphide as crystals [from light petroleum (b.p. 80—100 °C)], m.p. 127—129 °C (Found: C, 61.2; H, 4.9; N, 11.4. $C_{19}H_{18}ClN_3OS$ requires C, 61.4; H, 4.9; N, 11.3%); $\delta(CDCl_3)$ 8.20 (d, *J* 8 Hz, quinazolone H-5), 7.8—7.2 (m, 7 × ArH), 6.2—4.6 (m, NC*H*=CH_2), 2.40 (s, quinazolone CH_3), and 1.65 and 1.10 (d, *J* 6.5 Hz, 2 × CH_3). No coalescence of signals at δ 1.65 and 1.10 occurs up to 100 °C but the initial ratio of 1 : 3.3 changes to 1.84 : 1 after 1 h at 90 °C, $\nu_{max.}$ 1 680s, 1 590s, 1 000s, 920s, 810s, 760s, and 690s cm^{-1}.

N-(1-*Methylallyl*)-N-*phthalimido*-2-*nitrobenzenesulphenamide* (10). This was formed from *N*-aminophthalimide and *trans*-but-2-enyl 2-nitrophenyl sulphide. Chromatography over alumina with 4 : 1 light petroleum–ether eluted unchanged sulphide. Further elution with ether gave the *product* (32%) as pale yellow crystals (from ethanol), m.p. 125—127 °C (Found: C, 58.5; H, 4.2; N, 11.3. $C_{18}H_{15}N_3O_4S$ requires C, 58.5; H, 4.1; N, 11.4%); $\delta(CD_2Cl_2)$ 9.06 (d, *J* 9 Hz, benzene H-6), 8.26 (d, *J* 7 × 2 Hz, benzene H-3), 7.96—7.70 and 7.35 (m and dd, *J* 8, 8 Hz, 6 × ArH), 6.16—5.76 (m, H-2), 5.30br (d, *J* 5 Hz, H-3 *cis*), 5.05 (d, *J* 10 Hz, H-3 *trans*), 4.6—4.3 (m, H-1), and 1.34 (d, *J* 6.5 Hz, CH_3). Cooling to −24 °C gives two methyl doublets, δ 1.36 and 1.31, and two phenyl *o*-H doublets, δ 9.08 and 9.01, with coalescence at 0 °C, $\nu_{max.}$ 1 780m, 1 730s, 1 565s, 1 500s, 1 305m, 945m, 730s, and 705s cm^{-1}; *m/e* 396 (M^+), 314, 251, 250, 223, 215, 154, 138, 104 (base), 77, and 55.

N-(1-*Methylallyl*)-N-*phthalimido*-2,4-*dinitrobenzenesulphenamide* (11). This was formed from *N*-aminophthalimide and *trans*-but-2-enyl 2,4-dinitrophenyl sulphide. Chromatography over Kieselgel using 5 : 1 light petroleum–ethyl acetate eluted unchanged sulphide followed by the *product* (39%) as yellow crystals (from methanol–chloroform), m.p. 146—147 °C (Found: C, 51.7; H, 3.4; N, 13.4. $C_{18}H_{14}N_4O_6S$ requires C, 51.2; H, 3.4; N, 13.5%); $\delta(CDCl_3)$ 9.35, 9.28 (2 × d, *J* 9.5 Hz, benzene H-6), 9.05 (d, *J* 2.5 Hz, benzene H-3), 8.60 (dd, *J* 2.5, 9 Hz, benzene H-5), 7.84br (s, 4 × phthalimido H), 6.16—5.68 (m, :CH), 5.45—5.0 (m, :CH_2), 4.7—4.3 (m, C*H*CH_3), and 1.42 and 1.36 (2 × d, *J* 6.5 Hz, 2 × CH_3). On heating, these last two signals coalesce at 39 °C; those of phenyl *o*-H do likewise at 43 °C. At 48 °C one methyl doublet is present at δ 1.40, $\nu_{max.}$ 3 100w, 1 790w, 1 730s, 1 590s, 1 510s, 940s, 880s, 830s, and 720s cm^{-1}.

Bis-(2-*isopropylphenyl*) *Disulphide*.—2-Isopropylbenzenethiol (4.95 g) and iodine (7 g) were shaken for 1.5 h in chloroform (20 ml) and water (20 ml). Sodium carbonate was added until the solution was basic followed by sodium thiosulphate until excess of iodine was removed. The organic layer was separated and the aqueous layer extracted with more chloroform (20 ml). After washing the combined chloroform extracts with water, drying (Na_2SO_4) and evaporating gave an oil which was purified by chromatography over alumina using light petroleum. Crystallisation of the product from light petroleum (b.p. <40 °C) gave a sample (4 g, 81%), m.p. 46—52 °C (lit.,[20] 58.5—60 °C) whose n.m.r. spectrum indicated the compound was sufficiently pure to be used below, $\delta(CDCl_3)$ 7.7—6.8 (m, 8 × ArH), 3.5 (m, *J* 7 Hz, 2 × CH), and 1.2 (d, *J* 7 Hz, 4 × CH_3).

2-*Isopropylbenzenesulphenyl Chloride*.—To a saturated solution of chlorine in carbon tetrachloride (80 ml) at −5 °C was added bis-(2-isopropylphenyl) disulphide (4 g) in carbon tetrachloride (20 ml) over 15 min. The mixture was then evaporated under reduced pressure and the residue distilled, b.p. 110—120° at 0.7 mmHg (4.7 g, 95%), $\delta(CDCl_3)$ 7.9—7.1 (m, 4 × ArH), 3.7 (m, *J* 7 Hz, CH), and 1.3 (d, *J* 7 Hz, 2 × CH_3).

N-*Phthalimido*-4-*chlorobenzenesulphenamide* (20).—*N*-Aminophthalimide (5 g) was suspended in triethylamine (3.5 g) and dichloromethane (150 ml) with stirring at 0 °C. 4-Chlorobenzenesulphenyl chloride[21] (5.5 g) in dichloromethane (80 ml) was added over 40 min. After stirring for a further 2 h, the mixture was filtered to remove unchanged *N*-aminophthalimide (0.28 g), washed with water (2 × 20 ml), dried (Na_2SO_4), evaporated, and the residue chromatographed over alumina with 4 : 1 light petroleum–ethyl acetate which eluted bis-(4-chlorophenyl) disulphide, m.p. 69—70 °C (from light petroleum), identified by i.r. and mixed m.p. comparison with authentic material. Elution with ethyl acetate gave the *product* (3.45 g, 37%) as crystals (from ethanol), m.p. 156 °C (decomp.) (Found: C, 55.2; H, 3.0; N, 9.2. $C_{14}H_9ClN_2O_2S$ requires C, 55.2; H, 3.0; N, 9.2%); $\delta(CDCl_3)$ 7.87 (s, 4 × phthalimido H), 7.68—7.24 (AA'BB', 4-ClC_6H_4S), and 6.30 (s, exchanges with D_2O, NH), $\nu_{max.}$ 3 260s, 1 795w, 1 725m, 885s, 840s, 800s, and 705s cm^{-1}; *m/e* 306 and 304 (M^+), 162, 161, 158, 147, 144, 143, 104 (base), and 77.

N-(1,2-*Dihydro*-2-*oxoquinolin*-1-*yl*)-4-*chlorobenzenesulphenamide* (19).—1-Amino-2-quinolone (1.5 g) and triethylamine (1 g) were dissolved in dry THF (50 ml) and 4-chlorobenzenesulphenyl chloride (1.7 g) in dry THF (30 ml) was added dropwise with stirring at room temperature over 20 min. After a further 1 h, the mixture was filtered, evaporated, and the residue recrystallised from ethyl acetate–light petroleum giving the *product* (44%), m.p. 143—145 °C (decomp.) (Found: C, 59.6; H, 3.7; N, 9.3. $C_{15}H_{11}ClN_2OS$ requires C, 59.5; H, 3.7; N, 9.25%), $\delta(CDCl_3)$ 8.0br (s, exchanges with D_2O, NH), 7.6—7.1 (m, 8 × ArH), 7.66 (d, *J* 9.5 Hz, quinoline H-4), and 6.64 (d, *J* 9.5 Hz, quinoline H-3), $\nu_{max.}$ 3 220m, 1 650s, 1 595s, 850s, 820s, 760s, and 750s cm^{-1}. *m/e* 304 and 302 (M^+), 288, 286, 160, 159, 158, 145, 144, 143, 117, 108, 90, 89, and 62.

N-(1,2-*Dihydro*-2-*oxoquinolin*-1-*yl*)-2-*isopropylbenzenesulphenamide* (21).—1-Amino-2-quinolone (0.8 g) and triethylamine (0.53 g) were dissolved in dichloromethane (15 ml) and 2-isopropylbenzenesulphenyl chloride (0.95 g) in dichloromethane (20 ml) was added over 30 min with stirring at room temperature. The mixture was stirred for a further 30 min, then heated under reflux for 30 min. After cooling, the mixture was washed with hydrochloric acid (1% solution), water, dried (Na_2SO_4), and evaporated to give an oil which was chromatographed over alumina with 5 : 1 light petroleum–ethyl acetate giving bis-(2-isopropylphenyl) disulphide (30%). Further elution with ethyl acetate gave the *product* (27%) as crystals (from light petroleum-ethyl acetate), m.p. 117—119 °C (decomp.) (Found: C, 69.5; H, 5.7; N, 9.1. $C_{18}H_{18}N_2OS$ requires C,

69.65; H, 5.85; N, 9.0%), δ($CDCl_3$) 7.92 (s, exchanges with D_2O, NH), 7.66—7.04 (m, 8 × ArH and quinoline H-4), 6.60 (d, *J* 9.5 Hz, quinoline H-3), 3.38 (m, *J* 6.5 Hz, CH), and 1.05 (d, *J* 6.5 Hz, 2 × CH_3); at 220 MHz and −50 °C the doublet (δ 1.05) separated into two doublets, δ 1.09 and 1.1 (*J* 6.5 Hz), δ_C($CDCl_3$) 160.6 (>C=O), 150.4—115.7 (14 × ArC + C-4, C-3), 30.65 (CH), and 23.8 (2 × CH_3), $\nu_{max.}$ 3 200m, 1 650s, 1 595s, 825m, and 755m cm^{-1}.

N-(1,2-*Dihydro*-2-*oxoquinolin*-1-*yl*)-2,4-*dinitrobenzenesulphenamide* (22).—1-Amino-2-quinolone (1.42 g) and triethylamine (0.92 g) were dissolved in dichloromethane (70 ml) and 2,4-dinitrobenzenesulphenyl chloride (2.13 g) in dichloromethane (70 ml) was added dropwise at room temperature over a period of 30 min. The mixture was heated under reflux for 1 h then stirred overnight at room temperature. Bis-(2,4-dinitrophenyl) disulphide was separated and the solution washed with water, dried (Na_2SO_4), and evaporated. Chromatography of the residue over alumina using dichloromethane gave more bis-(2,4-dinitrophenyl) disulphide (total 0.5 g, 28%) identical with authentic material. Further elution with ethyl acetate, then 3 : 1 ethyl acetate–ethanol, gave the *product* (28%) as yellow crystals (from acetonitrile), m.p. 197 °C (decomp.) (Found: C, 50.4; H, 2.9; N, 15.9. $C_{15}H_{14}N_4O_5S$ requires C, 50.3; H, 2.8; N, 15.6%); δ[$(CD_3)_2SO$] 9.3 (s, exchanges with D_2O, NH), 9.0—8.7 (benzene H-3, -5, and -6), 8.0 (d, *J* 9.5 Hz, quinoline H-4), 7.9—7.2 (m, 4 × quinoline ArH), and 6.8 (d, *J* 9.5 Hz, quinoline H-3), $\nu_{max.}$ 3 200w, 1 650s, 1 590s, 1 510s, 1 340s, 840w, and 830w cm^{-1}; *m/e* 358 (M^+), 200, 199, 183, 159, 145 (base), 122, 117, and 89.

N-*Benzyl*-N-*isopropyl*-2-*nitrobenzenesulphenamide* (12). This was prepared using Raban's procedure [8] from benzylisopropylamine (4 g) and 2-nitrobenzenesulphenyl chloride (2.7 g).[22] The crude product (93%) was crystallised from methanol, m.p. 58—60 °C (Found: C, 63.6; H, 6.0; N, 9.3. $C_{16}H_{18}N_2O_2S$ requires C, 63.55; H, 6.0; N, 9.3%); δ($CDCl_3$) 8.2—7.95 (m, 2 × ArH), 7.6—7.0 (m, 7 × ArH), 4.16br (s, CH_2Ph), 3.36 [heptet, *J* 6.5 Hz, $CH(CH_3)_2$], and 1.15 (d, *J* 6.5 Hz, 2 × CH_3). At −4 °C, δ 4.16 becomes an AB system, J_{AB} 13.7 Hz (coalescence at 26 °C), and δ 1.15 becomes two doublets, δ 1.10 and 1.20 (*J* 6.5 Hz), $\nu_{max.}$ 1 600m, 1 580m, 1 510s, 1 350m, 1 310s, 770s, 750s, and 720s cm^{-1}.

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