Isatogens: Crystal Structure, Electron Density Calculations, and ^{13}C Nuclear Magnetic Resonance Spectra

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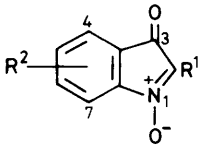
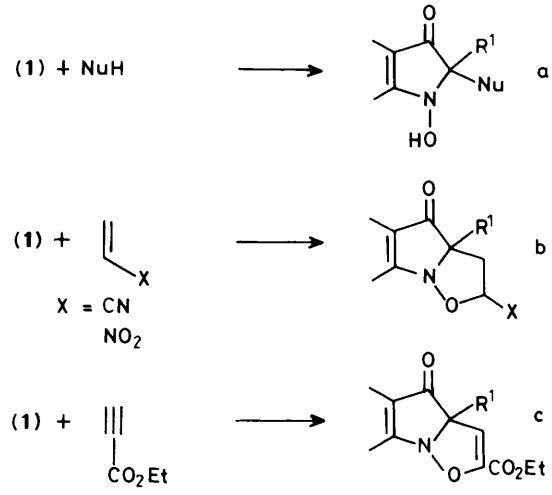
The structures of 2-phenylisatogen (**1a**) and 2-(2-pyridyl)isatogen (**1b**) have been determined by *X*-ray crystallography. In 2-phenylisatogen the isatogen ring and the phenyl ring are almost fully co-planar. In contrast, there is a dihedral angle of 45.5° between the isatogen ring and the 2-pyridyl ring in 2-(2-pyridyl)isatogen. The nitrogen atoms in the two ring systems are in a *transoid* relationship. Non-bonded separation distances in both compounds suggest strong dipolar associations involving the N–O bonds. MNDO Calculations using the experimental geometries of these two compounds show a high electron density at the C(2) position and at the nitrone oxygen atom O(1). ^{13}C N.m.r. spectra for a number of isatogens are reported and analysed. There is no obvious relationship between the calculated total valence electron densities and chemical shift values in these compounds. A σ_p^+ value of 0.343 has been calculated for the isatogen ring when attached to a phenyl ring. This value corresponds most closely to that for the phosphonate mono-anion. The structures, as well as chemical and biological activities of isatogens are discussed in the light of these results.

We have a long standing interest in the chemistry and biological activity of isatogens† (**1**). These compounds have a number of interesting and ambiguous chemical properties.[1] The major reactive site is C(2) which readily undergoes attack by a variety of nucleophiles[1] (Scheme 1a). Electron withdrawing substituents at this position, *e.g.* 2-pyridyl or methoxycarbonyl, increase this reactivity. In contrast, dipolar cycloaddition involves C(2) as an electron-rich centre[1,2] (Scheme 1b). This 'back polarisation' has been demonstrated in the addition of polarised alkenes to cyclic nitrones.[3] Theoretical studies have rationalised the reaction products from simple cyclic nitrones and polarised monosubstituted alkenes and alkynes[4] on the basis of LUMO and HOMO electron densities in both the nitrone and the dipolarophile components.[5] The carbonyl carbon atom C(3) in isatogens is much less reactive towards nucleophiles and related reagents.[1] The contrasting reactivities at the C(2) and C(3) atoms has led to the use of four canonical structures to represent the isatogen molecule, (i)—(iv), Figure 1. No *X*-ray crystallographic studies of isatogens have appeared. The determination of accurate bond lengths and angles would allow calculations of electron densities in these molecules and provide some understanding of the ambiguous chemical reactivities of these compounds.



	R^1	R^2
(**1**)	a; Ph	H
	b; 2-Pyridyl	H
	c; Ph	4-Me
	d; Ph	5-Me
	e; Ph	6-Me
	f; Ph	7-Me
	g; 3-Pyridyl	H

Isatogens also exhibit a wide range of biological activities,[1] including significant activity against a range of bacteria,[6] mycobacteria, both *M. tuberculosis*[7] and *M. leprae*,[8] and fungi.[9] Novel isatogens (**1**; R = 5-membered heteroaryl ring) have been patented as plant antifungal agents.[10] In mammalian systems isatogens are inhibitors of adenosine triphosphate (ATP) synthesis by mitochondrial preparations and antagonise the inhibitory (relaxant) effects of exogenous ATP on the smooth muscle of the *Taenia caeci* of the guinea pig. We have published two major structure-activity studies on the biochemistry and pharmacology of isatogens.[11] In both these studies the major reference compounds were the deep red 2-phenylisatogen (**1a**) and the orange-yellow 2-(2-pyridyl)isatogen (**1b**). The contrasting colours of these two compounds suggest that replacement of the phenyl by the 2-pyridyl group results in an increasing loss of planarity between the isatogen and 2-pyridyl rings. This may be an important correlate of certain biological activities and would be clearly identified in any crystallographic studies.



Scheme 1. Addition reactions of isatogens

In this paper we report the results of an *X*-ray crystallographic study of both 2-phenyl and 2-(2-pyridyl) isatogens (**1a,b**). MNDO Calculations were carried out using these experimental geometries to obtain charge densities and bond orders. The relationships between these data and

† isatogen = 3*H*-Indol-3-one 1-oxide.

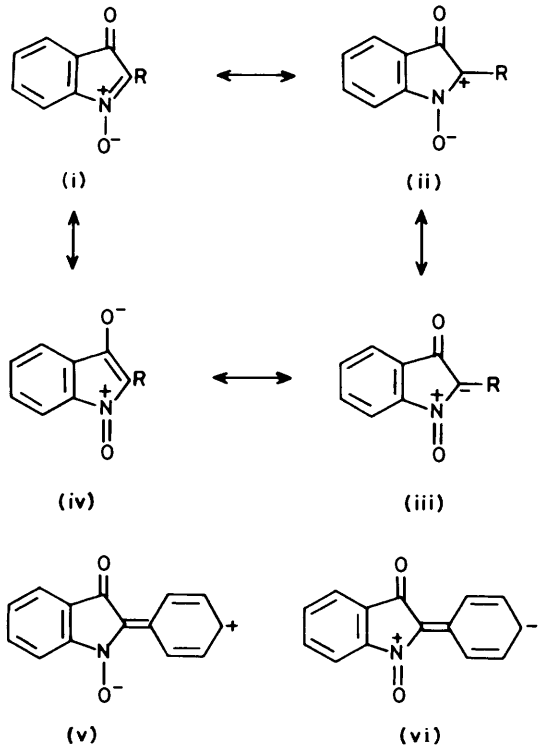


Figure 1. Canonical structures of isatogens

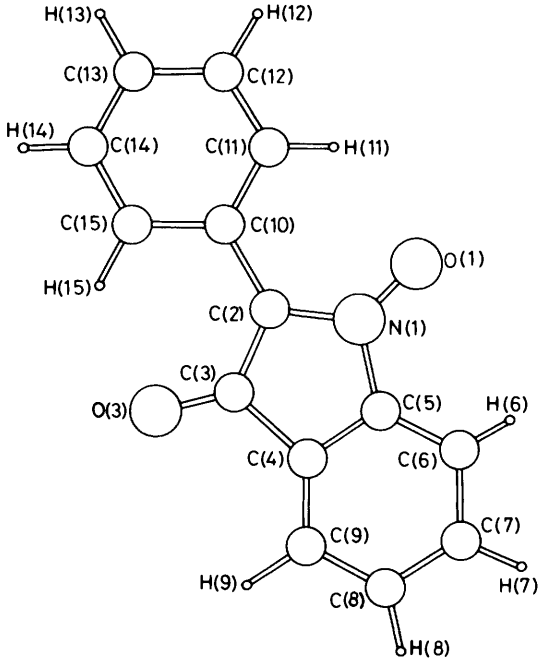


Figure 2. Perspective diagram of the structure of 2-phenylisatogen (**1a**) with atomic numbering

calculations and the ^{13}C spectra of isatogens (**1a**—**g**), and the chemical and biological activities of isatogens generally are discussed.

Molecular Geometry.—The crystal structures and atomic numbering of the isatogens (**1a**,**b**) are shown in Figures 2 and 3.

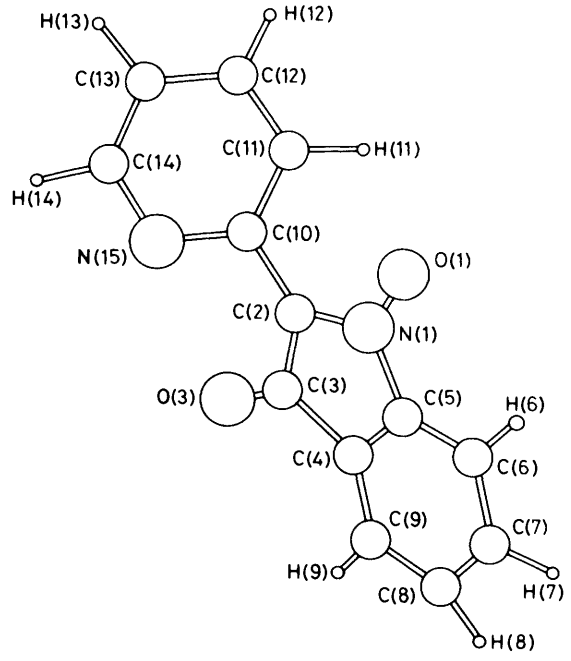


Figure 3. Perspective diagram of 2-(2-pyridyl)isatogen (**1b**) with atomic numbering

Table 1. Bond lengths (Å) and angles (°) for 2-phenylisatogen (**1a**) with e.s.d.s in parentheses

Bond	Bond length	Bond sequence	Bond angle
N(1)–O(1)	1.261(3)	C(5)–N(1)–C(2)	110.2(2)
N(1)–C(2)	1.372(3)	C(1)–N(1)–C(2)	128.7(2)
N(1)–C(5)	1.461(3)	O(1)–N(1)–C(5)	121.1(2)
C(2)–C(3)	1.430(3)	C(3)–C(2)–N(1)	106.7(2)
C(2)–C(10)	1.456(3)	C(10)–C(2)–N(1)	125.5(2)
C(3)–O(3)	1.232(3)	C(10)–C(2)–C(3)	127.8(2)
C(3)–C(4)	1.479(3)	C(4)–C(3)–C(2)	108.4(2)
C(4)–C(5)	1.369(3)	O(3)–C(3)–C(2)	127.8(2)
C(4)–C(9)	1.369(4)	O(3)–C(3)–C(4)	123.8(2)
C(5)–C(6)	1.360(4)	C(5)–C(4)–C(3)	106.7(2)
C(6)–C(7)	1.401(4)	C(9)–C(4)–C(3)	131.9(2)
C(7)–C(8)	1.382(5)	C(9)–C(4)–C(5)	121.5(2)
C(8)–C(9)	1.384(4)	C(4)–C(5)–N(1)	108.1(2)
C–C[a]	1.383(4) (av)	C(6)–C(5)–N(1)	128.9(2)
C–H	1.04 (av)	C(6)–C(5)–C(4)	123.0(2)
		C(7)–C(6)–C(5)	115.9(3)
		C(8)–C(7)–C(6)	121.4(3)
		C(9)–C(8)–C(7)	121.0(3)
		C(8)–C(9)–C(4)	117.2(3)
		C(11)–C(10)–C(2)	122.0(2)
		C(15)–C(10)–C(2)	119.7(2)
		C–C–C[a]	120.0(3) (av)

[a] Benzene ring.

Tables 1 and 2 list the bond distances and bond angles in (**1a**) and (**1b**) respectively. In both compounds the phenyl (2-pyridyl) rings and the isatogen ring are separately planar. In (**1a**) the isatogen ring and the phenyl ring are only marginally non-coplanar. The dihedral angle between the two rings systems being 7.0 (2.0)°. In contrast, there is a large dihedral angle of 45.5 (2.0)° between the planes of the isatogen and 2-pyridyl rings in (**1b**), Figure 3. Interestingly the N(1) and N(2) atoms are in a *transoid* relationship across the C(2)–C(10) bond. The repulsive forces, twisting the two rings out of a common plane, arise from the electrostatic repulsions between the negative charge on the sp^2

Table 2. Bond lengths (Å) and angles (°) for 2-(2-pyridyl)isatogen (**1b**) with e.s.d.s in parentheses

Bond	Bond length (Å)	Bond sequence	Angle (°)
N(1)–O(1)	1.280(4)	C(5)–N(1)–C(2)	111.6(3)
N(1)–C(2)	1.350(5)	O(1)–N(1)–C(2)	127.7(3)
N(1)–C(5)	1.462(4)	O(1)–N(1)–C(5)	120.6(3)
C(2)–C(3)	1.451(5)	C(3)–C(2)–N(1)	106.7(3)
C(2)–C(10)	1.449(5)	C(10)–C(2)–N(1)	123.8(3)
C(3)–O(3)	1.223(4)	C(10)–C(2)–C(3)	129.5(3)
C(3)–C(4)	1.469(5)	C(4)–C(3)–C(2)	107.4(3)
C(4)–C(5)	1.387(5)	O(3)–C(3)–C(2)	126.2(3)
C(4)–C(9)	1.372(5)	O(3)–C(3)–C(4)	126.4(3)
C(5)–C(6)	1.355(5)	C(5)–C(4)–C(3)	107.8(3)
C(6)–C(7)	1.389(6)	C(9)–C(4)–C(3)	132.9(3)
C(7)–C(8)	1.393(6)	C(9)–C(4)–C(5)	119.4(3)
C(8)–C(9)	1.385(6)	C(4)–C(5)–N(1)	106.4(3)
C–N[a]	1.343(5) (av)	C(6)–C(5)–N(1)	129.6(3)
C–C[a]	1.379(5) (av)	C(6)–C(5)–C(4)	123.9(3)
C–H	1.11 (av)	C(7)–C(6)–C(5)	116.3(4)
		C(8)–C(7)–C(6)	121.3(4)
		C(9)–C(8)–C(7)	120.4(4)
		C(8)–C(9)–C(4)	118.6(4)
		C(11)–C(10)–C(2)	121.5(3)
		N(15)–C(10)–C(2)	115.4(3)
		C–N–C[a]	116.2(3)
		C–C–C[a]	118.8(4)
		N–C–C[a]	123.8(4)

[a] Pyridine ring.

Table 3. N–O Bond distances (Å) in selected compounds

Compd. (Group)	Distance	Reference
–N=O	1.20	12
(**2**)	1.260	13
(**3**)	1.283	14
N–O·	1.27—1.30	12, 15
N–O–	1.44	12

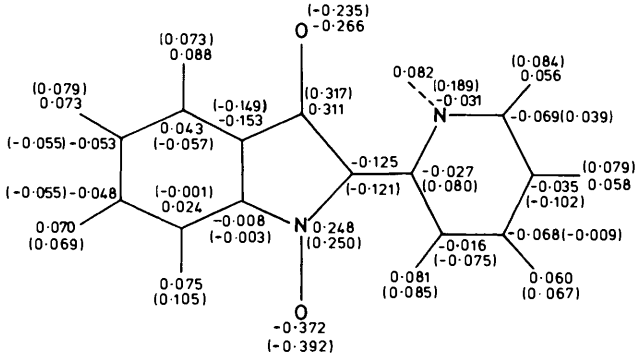
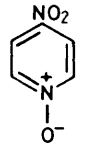


Figure 4. Charges in 2-phenylisatogen (**1a**) and in parentheses 2-(2-pyridyl)isatogen (**1b**); Z = CH (**1a**), N (**1b**)

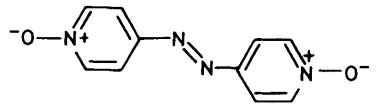
hybridised pyridyl ring nitrogen, −0.189, and the negative charges on O(1), −0.392, and O(3), −0.235, the nitrogen being further from O(1).

There are major differences in bond lengths in the O(3)–C(3)–C(2)–N(1)–O(1) moiety of both molecules which are summarised in Tables 1–3. The N(1)–O(1) distances are of particular interest. Some N–O bond distances in related structures are given in Table 3. These show that the N(1)–O(1) bond in (**1a**) has considerable π-character (π-bond order 0.59). The N=O bond distance is 1.20 Å. 4-Nitropyridine 1-oxide (**2**) with an N–O bond length of 1.260 Å has significant double bond character. In compound (**1b**) the N(1)–O(1) bond distance corresponds to the essentially σ bond found in (*E*)-4,4′-azopyridine 1,1′-dioxide (**3**) and the three electron bonds commonly found in many N–O· radicals. The virtually identical C(5)–N(1) bond distances in structures (**1a**) and (**1b**) show that there is no delocalisation of electrons through the benzene ring.[12] Overall, the canonical structures (iii) and (iv)—shorter C(2)–C(3) and longer C(3)–O(3) distances respectively—are major contributors to (**1a**) whilst (i) and (ii)—longer C(2)–C(3) and shorter C(3)–O(3) distances—are major contributors to (**1b**), Figure 1. The curiously irregular bond lengths in the benzene ring are also noteworthy. The very similar distances for the C(2)–C(10) bond in both (**1a**) and (**1b**) corresponding to very low π-character indicates that there is only a small mesomeric effect transmitted from the isatogen ring to the phenyl (2-pyridyl) ring.

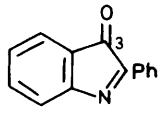
The charge separation in the N(1)–O(1) bonds of compounds (**1a**) and (**1b**) is important. The major dipolar intermolecular interaction is between N(1) ··· O(1) with separation distances of 3.212 Å (**1a**) and 3.127 Å (**1b**); crystal cell data are available on request.



(**2**)



(**3**)



(**4**)

MNDO Calculations.—These were performed for compounds (**1a**) and (**1b**) using the experimental geometries and for two typical dipolarophiles, nitroethene and acrylonitrile, with geometry optimization. Although C(2) in the isatogens has a significant negative charge (Figure 4) nucleophiles attack C(2) and not C(3) (Scheme 1a), which carries a large positive charge. However, inspection of the lowest unoccupied orbitals (LUMO) of the isatogens (Table 4) shows that the coefficient at C(2) is much greater than that at C(3), correctly predicting the site of attack.

Scheme 1b shows a typical dipolar addition reaction of isatogens, the regiospecificity of which may be rationalized by considering the frontier orbitals.[4,5] Inspection of the HOMO and LUMO energies for the isatogens and nitroethene shows that the lower energy difference, and hence major interaction, is between the HOMO of the isatogen and the LUMO of nitroethene. In the case of acrylonitrile the two HOMO–LUMO energy differences are very similar and therefore both HOMO–LUMO interactions will be of importance. However, since the HOMO coefficients at C(1) and C(2) are virtually identical it will again be the isatogen HOMO–dipolarophile LUMO interaction which controls the regiospecificity. In both isatogens the HOMO coefficient at O(1) is slightly greater than that at C(2) but these require correction for the different bond integrals during reaction. Multiplying the coefficients by the C–O and C=C bond integral quoted by Houk *et al.*[5b] for a distance of 1.75 Å (−5.38 and −6.22 eV) indicates that C(2) has the larger corrected coefficient. (This effect is even greater at larger separation). Hence C(2) of the isatogen is predicted to bond to the dipolarophile carbon with the higher LUMO

Table 4. HOMO and LUMO energies and coefficients for isatogens (**1a,b**), nitroethylene, and acrylonitrile

Isatogens

	Orbital	Energy/(eV)	O(1)	N(1)	Coefficients C(2)	Coefficients C(3)
(**1a**)	HOMO	−8.66	−0.48	0.24	0.46	0.04
	LUMO	−1.85	0.35	−0.39	0.34	0.28
(**1b**)[a]	HOMO	−9.6	−0.54	0.21	0.53	0.02
	LUMO	−1.75	0.33	−0.38	0.35	0.26

Dipolarophiles $H_2C(2)=C(1)HX$

	Orbital	Energy/(eV)	Coefficients C(1)	Coefficients C(2)
X = NO_2	HOMO − 1	−11.63	0.71	0.65
	HOMO	−11.43	Located on oxygens of nitro group	
	LUMO	−1.01	−0.42	0.62
X = CN	HOMO	−10.62	0.65	0.65
	LUMO	0.03	−0.57	0.70

[a] Since the isatogen and 2-pyridyl rings are not coplanar there is not complete σ–π separation in this molecule. The coefficients shown are for the $2p_z$ orbits with the isatogen ring the *x*–*y* plane.

coefficient, *i.e.* C(2) (Table 4), leading to the experimentally observed isomer.

^{13}C *N.m.r. Spectra.*—The ^{13}C chemical shifts of the isatogens (**1a**—**g**) are given in Table 5, and to avoid confusion the atoms are numbered as for the crystal structures. The assignments have been made using empirical additivity rules[16–18] for aromatic and heteroaromatic compounds and using the values for carbonyl and nitro substituents for C(3) and N(1) of the isatogen ring respectively. Quaternary carbon atoms were identified by their small integral values and the use of a relaxation agent. The chemical shifts of the carbon atoms in the isatogen ring moiety O(3)–C(3)–C(2)–N(1)–O(1) remain fairly constant. There was no relationship with total electron/charge densities or π-electron densities not shown. The relationships between electron/charge and ^{13}C chemical shifts are contradictory.[16] A number of interesting points can be made from the present data. The C(3) chemical shifts lie in the normal conjugated or cross-conjugated ketone range[17] although the corresponding atom in the 2-phenylindolone (**4**) has a significantly higher value. The C(2) chemical shifts, 119.7 to 122.8 p.p.m., all indicate a high degree of shielding relative to the corresponding azomethine in compound (**4**), in which C(2) resonates at 160.5 p.p.m. Table 6 lists the chemical shift changes for a number of systems involving the transformation of C=N–O to C=N–. The effect is greatest for the isatogen-indolone change but still large in the acyclic nitrone–azomethine system. The changes for aromatic azine *N*-oxides to azines are much smaller. In each case the authors invoke the back polarisation associated with *N*-oxides as the basis of these chemical shift differences. In the pyridine *N*-oxide/pyridine system the chemical shift changes at C(2), C(3), and C(4) follow the pattern of π-electron density changes at these positions.[23] The low chemical shift value for C(6), *ca.* 116 p.p.m. is similar to that observed in quinoline *N*-oxides (119.7 p.p.m.), and probably arises from the same space-charge interaction between the negative charge on the *N*-oxide oxygen atom and the *peri*-hydrogen atom.[24] The corresponding carbon atom in simple indoles also has a low chemical shift.[25]

A further point of interest is the average chemical shift, 130.52 p.p.m., of the C(13) atom in the 2-phenylisatogens (**1a**, **c**—**f**), Table 5. The relationship between ^{13}C chemical shifts at the *para* carbon atom in monosubstituted benzenes, and the Hammett σ_p and σ_p^+ values of the substituents is well established.[16–18] We have derived the regression equation $\sigma_p^+ = 0.1126\ \delta_C + 0.1154$; $n = 12$, $r = 0.98$, from published data.[26] The chemical shifts, δ_C, were recorded for chloroform solutions using benzene as an internal standard. Taking 128.50 p.p.m. as the ^{13}C chemical shift of benzene relative to tetramethylsilane, a figure of 2.02 p.p.m. (130.52—128.5) is obtained for the *para* carbon atom in 2-phenylisatogens and 3.1 p.p.m. (131.6—128.5) for the corresponding position in the 2-phenylindolone (**4**). The calculated σ_p^+ values using the regression

Table 5. ^{13}C Chemical shifts and integral values for isatogens (**1a**—**g**) and 2-phenylindol-3-one (**4**)

Compd.	C(2)	C(3)	C(4)	C(5)	C(6)	C(7)	C(8)	C(9)	C(10)	C(11)	C(12)	C(13)	C(14)	C(15)*	Me
(**1a**)	122.8	186.7	133	147.8	114.8	134.7	131.1	121.9	125.9	127.8	128.5	130.6	128.5	127.8[a]	
	0.11	0.57	0.06	0.98	1.41	1.49	1.57	1.43	0.25	3.14	2.85	1.76	2.85	3.14[b]	
(**1b**)	122.7	185.0	130.3	145.5	114.4	134.6	131.8	121.8	147.5	124.1	136.3	124.8	150.3	N	
	0.21	NI[c]	NI	0.20	1.69	1.86	2.01	1.78	0.12	1.90	1.55	1.59	1.52		
(**1c**)	119.7	187.2	134.0	147.8	111.9	134.9	133.8	130.4	125.8	128.0	128.5	130.4	128.5	128.0	17.3
	NI	NI	NI	NI	0.31	0.62	0.72	0.06	NI	0.76	0.93	0.57	0.99	0.76	0.12
(**1d**)	122.9	187.2	133.0	145.8	114.0	134.9	142.0	122.3	125.9	127.8	128.5	130.5	128.5	127.8	21.6
	0.06	0.03	NI	0.03	0.45	0.42	0.13	0.56	0.14	1.10	1.00	0.54	1.00	1.10	0.31
(**1e**)	120.4	186.7	132.0	148.3	115.0	146.7	131.3	121.6	125.9	127.8	128.5	130.7	128.5	127.8	22.4
	0.18	0.65	0.03	0.15	0.88	0.27	0.69	0.81	0.22	1.27	1.36	0.74	1.36	1.27	0.55
(**1f**)	122.0	187.2	132.7	143.5	123.7	139.6	130.7	119.8	125.9	127.7	128.4	130.4	128.4	127.7	17.3
	NI	0.15	0.19	0.18	0.27	1.47	1.44	1.42	0.41	3.24	3.01	1.55	3.01	3.24	1.08
(**1g**)	122.5	185.4	130.3	147.7	114.3	134.2	131.6	121.9	122.6	135.0	123.3	150.8	N	148.6	
	NI	0.51	0.24	0.35	1.84	3.20	2.97	2.56	0.88	2.58	2.45	1.83		1.69	
(**4**)	160.5	192.8	122.8	159.4	121.5	136.1	124.0	127.7	129.8	128.9	128.2	131.6	128.2	128.9	
	2.03	1.73	2.27	2.48	7.48	8.07	7.48	8.74	2.74	15.80	15.83	7.74	15.83	15.80	

* The atoms are numbered as in Figures 2 and 3. [a] Chemical shifts relative to $SiMe_4$ in $CHCl_3$ solution. [b] Integral values. [c] Not integrated.

Table 6. ^{13}C Chemical shift differences for various $C=\overset{+}{N}-\bar{O}$ to C=N transformations

Compd.	p.p.m.	References
(**1a**) ⟶ (**4**)	37.7	Table 5
(**5**) ⟶ (**6**)	25.8	19—22
(**7**) ⟶ (**8**)	11.3	23
(**9**) ⟶ (**10**)	14.4	24
(**11**) ⟶ (**12**)	16.3	24

(**5**) = α-phenyl-*N*-phenylnitrone; (**6**) = *N*-benzylideneaniline; (**7**) = pyridine *N*-oxide; (**8**) = pyridine; (**9**) = quinoline *N*-oxide; (**10**) = quinoline; (**11**) = isoquinoline *N*-oxide; (**12**) = isoquinoline.

equation are 0.343 and 0.464 respectively. The value for the isatogen ring is uncommon and corresponds most closely to those for the methylsulphinyl group σ_p^+ 0.386, and the phosphonate anion, σ_p^+ 0.288.[27] The identification of the latter negatively charged polarisable grouping is intriguing, especially in view of the effect of isatogens on ATP synthesis and pharmacological activity.[11] This analysis suggests that simple phenylphosphonic acids and their esters may well repay careful study in those biological systems in which isatogens have shown interesting and novel activity. The σ_p^+ value for the 2-phenylindolone (**4**) corresponds most closely to that of a carboxy or ethoxycarbonyl group, 0.472.[27] It is not surprising that the indolone ring substituent should approximate electronically to these groups.

Experimental

Synthesis of Isatogens.—2-Phenylisatogen (**1a**) was prepared by cyclisation of 1-(2-nitrophenyl)-2-phenylethyne with nitrosobenzene in chloroform,[28] or by heating copper(I) phenylacetylide with 2-iodonitrobenzene in dry pyridine.[29]

4-Methyl-2-phenylisatogen (**1c**) was prepared by refluxing copper(I) phenylacetylide with 2-iodo-3-methylnitrobenzene,[30] as red needles (butanol) (73%), m.p. 127—128 °C (Found: C, 75.9; H, 4.6; N, 5.8. $C_{15}H_{11}NO_2$ requires C, 75.95; H, 4.64; N, 5.91%).

2-(2-Pyridyl)isatogen (**1b**) was prepared in good yield by the method of Ruggli and Cuenin;[31] purification of the intermediates at each stage of the reaction led to consistent yields.[32]

The isatogens (**1d—f**) were prepared by coupling the appropriate methyl-2-iodonitrobenzene[30,33] with phenylacetylene in triethylamine using bis(triphenylphosphine)palladium(II) dichloride,[34] and cyclising the resulting acetylenes by refluxing in chloroform with nitrosobenzene;[35a] full details will be published elsewhere.[35b] The same method also gave compounds (**1b,g**) from 2-iodonitrobenzene and the appropriate ethynylpyridines.[36]

2-Phenylindol-3-one (**4**) was prepared by a standard method.[37]

Crystal Structures.—Single crystals of 2-phenylisatogen (**1a**) and 2-(2-pyridyl)isatogen (**1b**) were obtained by slow evaporation of saturated ethanolic solutions of the compounds at low temperature. Optical examination of the crystals suggested that they were isomorphous, orthorhombic, and of *mm* symmetry. Preliminary unit cell dimensions and space groups were determined from Weissenberg and precession photographs. Accurate unit cell parameters were obtained from the centred settings of 25 reflections of an ENRAF-NONIUS CAD-4 diffractometer at the Department of Chemistry (S.E.R.C. Data Collection Centre), Queen Mary College, University of London. Intensity data were also collected at the above laboratory using monochromated Cu-K_α (λ = 1.541 78 Å) radiation and the θ—2θ scan method in the 2θ range 3.0 to 60.0 for (**1a**) and (**1b**). A total of 1 837 unique reflections were collected for (**1a**) of which 1 145 had intensities $2.5\sigma(I)$; 1 536 unique reflections were measured for (**1b**) of which 843 had intensities $>2.5\sigma(I)$. The data were corrected for Lorentz and polarisation effects.

The lists of atomic co-ordinates for hydrogen atoms, the equations of least-square mean planes, and the anisotropic thermal parameters for compounds (**1a,b**) have been deposited as a Supplementary Publication [Sup. No. 56515 (11 pp)].* The calculated and observed structure factors are available on request from the Editorial Office.

* For details of the Supplementary Publications Scheme, see 'Instructions for Authors,' (1986), *J. Chem. Soc., Perkin Trans. 1*, 1986, Issue 1.

Crystal Data.—Compound (**1a**). $C_{14}H_9NO_2$, M = 223.22. Orthorhombic, a = 11.464(1), b = 7.831(1), c = 23.979(3) Å, U = 2 152.72 Å^3, D_c = 1.38 g cm^{-3}, Z = 8, (Cu-K_α) = 6.70 cm^{-1}, $F(000)$ = 928, space group $Pbca$ (D_{2h}^{15} No. 61) from reflection conditions o,k,l, $k = 2n$; h,o,l, $l = 2n$; h,k,o, $h = 2n$.

Compound (**1b**). $C_{13}H_8N_2O_2$, M = 224.19. Orthorhombic, a = 11.926(1), b = 7.450(2), c = 23.252(3) Å, U = 2 066.1 Å^3, D_c = 1.44 g cm^{-3}, Z = 8, (Cu-K_α) = 7.29 cm^{-1}, $F(000)$ 928, space group $Pbca$ (D_{2h}^{16} No. 61) from reflection conditions o,k,l, $k = 2n$; h,o,l, $l = 2n$; h,k,o, $h = 2n$.

Structure Solution and Refinement.—The crystal structures of both molecules were solved by direct methods using the automated centrosymmetric routine in the SHELX[38] program. Hydrogen atom co-ordinates were obtained by difference Fourier methods but were not refined. Collective isotropic temperature factors were allocated separately to the H-atoms of the isatogen molecule and its 2-substituted components. For compound (**1a**) final U values of 0.102(5) Å^2 and 0.112(5) Å^2 were obtained for the H-atoms of the heterocyclic and phenyl groups respectively. For compound (**1b**) the corresponding U values were 0.090(6) Å^2 and 0.087(6) Å^2. Scattering factors were

Table 7. Final fractional co-ordinates ($\times 10^5$) for the non-H atoms of compound (**1a**) with e.s.d.s in parentheses and *B*eq values

Atom	*x/a*	*y/b*	*z/c*	*B*eq (Å^2)
N(1)	18 180(18)	5 864(26)	6 569(9)	4.5(1)
O(1)	26 879(15)	−3 808(25)	7 170(8)	5.7(1)
O(3)	−5 301(15)	31 493(24)	9 801(7)	5.6(1)
C(2)	11 020(19)	12 620(30)	10 585(10)	3.6(1)
C(3)	2 593(19)	22 884(30)	7 743(10)	3.6(1)
C(4)	4 894(21)	21 797(30)	1 685(10)	3.6(1)
C(5)	14 435(21)	11 478(31)	1 041(10)	3.6(1)
C(6)	18 988(25)	7 427(36)	−4 029(12)	5.1(1)
C(7)	13 452(28)	14 781(46)	−8 648(12)	5.8(2)
C(8)	3 753(28)	25 097(42)	−8 040(12)	4.8(1)
C(9)	−675(24)	28 842(35)	−2 811(12)	3.9(1)
C(10)	12 040(21)	09 632(29)	16 559(10)	3.9(2)
C(11)	21 581(24)	01 176(38)	18 862(12)	5.4(2)
C(12)	22 244(29)	−1 368(46)	24 573(14)	6.5(2)
C(13)	13 502(30)	4 399(42)	28 054(12)	6.0(2)
C(14)	4 188(26)	12 692(52)	25 806(12)	6.3(2)
C(15)	3 244(24)	15 427(40)	20 150(12)	5.4(1)

*B*eq defined by $\frac{8\pi^2}{3}$ trace $\tilde{U}$

Table 8. Final fractional co-ordinates ($\times 10^5$) for the non-H atoms of compounds (**1b**) with e.s.d.s in parentheses and *B*eq values

Atom	*x/a*	*y/b*	*z/c*	*B*eq (Å^2)
N(1)	19 200(24)	826(43)	7 478(13)	4.0(2)
O(1)	28 486(19)	4(38)	8 246(11)	4.9(2)
O(3)	−5 228(20)	30 319(39)	10 721(10)	5.2(1)
C(2)	11 891(28)	13 926(53)	11 524(15)	3.3(2)
C(3)	2 802(27)	22 794(50)	8 505(15)	3.2(2)
C(4)	5 162(29)	21 436(50)	2 319(14)	3.3(2)
C(5)	15 207(28)	12 284(51)	1 676(14)	3.3(2)
C(6)	19 877(30)	8 304(59)	−3 479(16)	4.1(2)
C(7)	13 950(35)	13 742(63)	−8 319(17)	4.7(2)
C(8)	3 885(38)	23 120(58)	−7 840(16)	4.7(2)
C(9)	−553(29)	27 010(60)	−2 478(18)	4.4(2)
C(10)	13 437(29)	11 903(52)	17 640(15)	3.4(2)
C(11)	23 764(33)	14 127(60)	20 290(16)	4.2(2)
C(12)	24 694(37)	11 106(63)	26 072(16)	4.9(2)
C(13)	15 461(39)	5 176(59)	29 107(17)	4.9(2)
C(14)	05 575(36)	2 758(63)	26 172(18)	5.2(2)
N(15)	04 282(26)	5 510(48)	20 515(13)	4.5(2)

Table 9. A comparison of torsion angles (°) for compounds (**1a**) and (**1b**)

(1a)		(1b)	
(Angle)	(°)	(Angle)	(°)
N(1)–C(2)–C(10)–C(11)	9.0	N(1)–C(2)–C(10)–C(11)	−45.0
N(1)–C(2)–C(10)–C(15)	−171.5	N(1)–C(2)–C(10)–N(15)	135.5
C(3)–C(2)–C(10)–C(11)	−171.5	C(3)–C(2)–C(10)–C(11)	135.0
C(3)–C(2)–C(10)–C(15)	8.5	C(3)–C(2)–C(10)–N(15)	−44.5

calculated from an analytical approximation. Full matrix refinement with anisotropic temperature factors for the non-H atoms and a weighting scheme of the form $w = 1.0000/[\sigma^2(F_o) + 1.0000(F_o)^2]$ gave final R and Rw of 0.0456 and 0.0676 for (**1a**), with 0.0456 and 0.0676 for (**1b**).

Final atomic parameters are listed in Tables 7 and 8, bond lengths and angles are in Tables 1 and 2. Some relevant torsion angles are given in Table 9. Figures 2 and 3 contain perspective diagrams of (**1a**) and (**1b**) with atomic labelling. Unit cell contents for (**1a**) and (**1b**) are given in deposited material.

^{13}N.m.r. Spectra.—The spectra of the isatogens (**1a**—**g**) were run in chloroform solution using tetramethylsilane as an internal standard on a Bruker WH 180 spectrometer at the Physico-Chemical Measurements Unit, Aldermaston. The spectrum of 2-phenylindol-3-one (**4**) was run in the same way using a WP 200 spectrometer at the University of Edinburgh.

Calculations.—The MNDO calculations were performed using a redimensional version of the standard MNDO program[29] implemented on a Harris S100 computer at the computer centre, Sunderland Polytechnic.

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