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Structures of Three Photochromic Compounds and Three Non-Photochromic Derivatives; the Effect of Methyl Substituents

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Abstract. (1) 1,3,3-Trimethylspiro{indoline-2,3'-(3'H)-[1,4]oxazino(3'H)-[3,2-f][quindine}, $C_{21}H_{19}N_3O$, $M_r = 329\cdot4$, monoclinic, $P2_1/n$, $a = 10\cdot999$ (1), $b = 14\cdot983$ (1), $c = 21\cdot351$ (2) Å, $\beta = 97\cdot259$ (8)°, $V = 3490\cdot4$ Å^3, $Z = 8$, $D_x = 1\cdot253$ g cm^{-3}, λ(Cu $K\alpha$) = $1\cdot54184$ Å, $\mu = 5\cdot9$ cm^{-1}, $F(000) = 1392$, $T = 295$ K, $R = 0\cdot064$ for 3999 unique observed reflections. (2) 1,2',3,3-Tetramethylspiro{indoline-2,3'(3'H)-[1,4]-oxazino[3,2-f]quindine}, $C_{22}H_{21}N_3O$, $M_r = 343\cdot4$, monoclinic, $P2_1/c$, $a = 7\cdot3093$ (4), $b = 22\cdot3464$ (14), $c = 10\cdot9473$ (8) Å, $\beta = 94\cdot848$ (5)°, $V = 1781\cdot7$ Å^3, $Z = 4$, $D_x = 1\cdot280$ g cm^{-3}, μ(Cu $K\alpha$) = $6\cdot0$ cm^{-1}, $F(000) = 728$, $T = 295$ K, $R = 0\cdot043$ for 2574 unique observed reflections. (3) 5-Methoxy-1,3,3-trimethylspiro{indoline-2,3'(3'H)-[1,4]oxazino[3,2-f]-quindine}, $C_{22}H_{21}N_3O_2$, $M_r = 359\cdot4$, monoclinic,

$P2_1/n$, $a = 11\cdot5201$ (5), $b = 10\cdot7143$ (5), $c = 16\cdot0914$ (7) Å, $\beta = 108\cdot075$ (4)°, $V = 1888\cdot1$ Å^3, $Z = 4$, $D_x = 1\cdot264$ g cm^{-3}, μ(Cu $K\alpha$) = $6\cdot3$ cm^{-1}, $F(000) = 760$, $T = 295$ K, $R = 0\cdot061$ for 2091 unique observed reflections. (4) 5-Methoxy-1,2',3,3-tetramethylspiro{indoline-2,3'(3'H)-[1,4]oxazino-[3,2-f]-quindine}, $C_{23}H_{23}N_3O_2$, $M_r = 373\cdot5$, monoclinic, $P2_1/n$, $a = 9\cdot9249$ (5), $b = 16\cdot7437$ (8), $c = 24\cdot0188$ (8) Å, $\beta = 100\cdot299$ (3)°, $V = 3927\cdot1$ Å^3, $Z = 8$, $D_x = 1\cdot263$ g cm^{-3}, μ(Cu $K\alpha$) = $6\cdot2$ cm^{-1}, $F(000) = 1584$, $T = 295$ K, $R = 0\cdot062$ for 3246 unique observed reflections. (5) 1',3',3'-Trimethyl-6-nitrospiro[benzopyran-2(2H),2'-indoline], $C_{19}H_{18}N_2O_3$, $M_r = 322\cdot4$, monoclinic, $P2_1/n$, $a = 16\cdot146$ (1), $b = 10\cdot979$ (1), $c = 19\cdot728$ (1) Å, $\beta = 105\cdot826$ (5)°, $V = 3364\cdot6$ Å^3, $Z = 8$, $D_x = 1\cdot273$ g cm^{-3}, μ(Cu $K\alpha$) =

6.7 cm^{-1}, $F(000) = 1360$, $T = 295$ K, $R = 0.054$ for 4265 unique observed reflections. [A previous determination of the same structure has been reported by Karaev, Furmanova & Belov (1982). *Dokl. Akad. Nauk. SSSR*, **262**, 877–880]. (6) $1',3,3',3'$-Tetramethyl-6-nitrospiro[benzopyran-2($2H$),2'-indoline], $C_{20}H_{20}N_2O_3$, $M_r = 336.4$, orthorhombic, *Pbcn*, $a = 12.923$ (1), $b = 12.605$ (1), $c = 21.234$ (2) Å, $V = 3458.9$ Å^3, $Z = 8$, $D_x = 1.292$ g cm^{-3}, μ(Cu $K\alpha$) = 6.7 cm^{-1}, $F(000) = 1424$, $T = 295$ K, $R = 0.047$ for 2048 unique observed reflections. The structures of three photochromic compounds are compared with their methylated analogues which do not exhibit the photochromic effect in the visible region. All of the compounds consist of a substituted indoline ring orthogonally linked through a spiro carbon to either a benzoxazine ring or to a nitro-substituted benzopyran ring, with the non-photochromic compounds methyl substituted at the C atom adjacent to the spiro carbon on the non-indole ring system. Methyl substitution induces steric strain, which distorts the rings and hinders the geometric rearrangement necessary for photochromic activity.

Introduction. Photochromism, the reversible change of colour upon exposure to light, is a phenomenon of interest because of the potential commercial uses of such materials for textile dyes, as printing inks, in ophthalmic lenses and as optical storage media. Synthetic efforts are often directed at tuning the properties of molecules and systems to vary colour, intensity, reaction rate, half-life and polarity (Bertelson, 1971).

The photochromic molecules of this study are composed of two ring systems that are joined at a spiro carbon. The rings contain localized, mutually orthogonal, π-electron systems and absorb in the ultraviolet (UV) region of the electromagnetic spectrum. Upon UV irradiation at a compound-specific wavelength, bond rupture occurs between the spiro carbon and the O atoms, whereupon the compound undergoes a geometric rearrangement such that all rings become coplanar, with concomitant increased π-electron delocalization. This lowers the energy of absorption, giving rise to a visible transition. As the cycle is repeated, the forward reaction is driven by UV and the reverse reaction is driven thermally and/or photolytically.
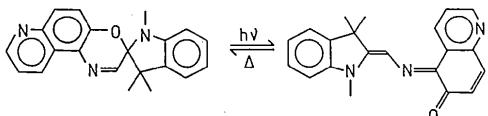
In order to study the molecular and electronic structure of these materials, a series of compounds was synthesized with a range of substituents and

subjected to X-ray diffraction analysis. The structures are represented diagrammatically below.
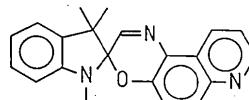
(1) 1,3,3-Trimethylspiro{indoline-2,3'($3'H$)-[1,4]oxazino[3,2-*f*]-quinoline}
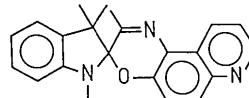
(2) 1,2',3,3-Tetramethylspiro{indoline-2,3'($3'H$)-[1,4]oxazino[3,2-*f*]-quinoline}
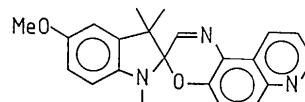
(3) 5-Methoxy-1,3,3-trimethylspiro{indoline-2,3'($3'H$)-[1,4]oxazino-[3,2-*f*]quinoline}
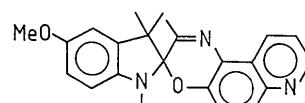
(4) 5-Methoxy-1,2',3,3-tetramethylspiro{indoline-2,3'($3'H$)-[1,4]-oxazino[3,2-*f*]quinoline}
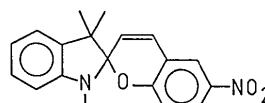
(5) $1',3',3'$-Trimethyl-6-nitrospiro[benzopyran-2($2H$),2'-indoline]
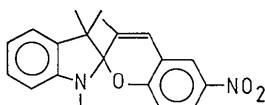
(6) $1',3,3',3'$-Tetramethyl-6-nitrospiro[benzopyran-2($2H$),2'-indoline]

A brief account of a previous structure determination for (5) has been given by Aoto, Nakamura, Maeda, Tomotake & Murayama (1989).

Experimental. All reactions were carried out under an atmosphere of dry dinitrogen using standard Schlenk techniques. All solvents were dried over appropriate drying agents and distilled immediately prior to use. ^{1}H and ^{13}C NMR spectra were recorded on a Bruker AM300 spectrometer operating at 300.133 and 75.469 MHz respectively. Spectra are referenced to Me$_4$Si (0.0 p.p.m.), positive values to high frequency. High accuracy mass measurements were performed using a VG ZAB mass spectrometer. The oxindoles used in the synthesis of the $2'$-

methylspiro compounds, (2) and (4), were prepared by permanganate oxidation of the corresponding 2-methylene-1,3,3-trimethylindolines.

Synthesis. (1) and (3): these were prepared and characterized as described by Kwak & Hurditch (1984).

(2): Ethyllithium (30 cm^3 of a 1·4 M solution in benzene) was added to a 100 cm^3 flask and cooled to 273 K and then a 1 M solution of 1,3,3-trimethyloxindole (2·60 g, 16·0 mmol) in diethyl ether was added at a rate such that the reaction temperature remained below 283 K. After complete addition, the reaction mixture was allowed to warm to room temperature and was then refluxed for 4 h. After cooling, the excess ethyllithium was quenched by dropwise addition of water, after which the solution was washed with saturated NaCl, dried (K$_2$CO$_3$), filtered and the solvent removed under reduced pressure. The crude 2-ethylidene-1,3,3-trimethylindoline was dissolved in ethanol (60 cm^3) and heated to reflux. Over a 1 h period, solid 5-nitroso-6-quinolinol (1·74 g, 10·0 mmol) was added and the resulting mixture refluxed for a further 4 h. After cooling and removal of solvent, the product was isolated by flash chromatography (SiO$_2$, 230–400 mesh, 20% ethanol/hexane) as an oil. Crystallization from hexane afforded 0·33 g (0·96 mmol, 9·6%) of (2) as tan microcrystals (m.p. 427–427·5 K). X-ray quality crystals were obtained by slow evaporation of an acetone solution. Spectroscopic data for (2): NMR, ^{1}H (CDCl$_3$) δ 1·20 (s, 3H, Me), 1·26 (s, 3H, Me), 2·33 (s, 3H, 2'-Me), 2·93 (s, 3H, N-Me), 6·59 [dd, 1H, H4, J(H4,H5) = 7·7 Hz, J(H4,H6) = 0·7 Hz], 7.20 [ddd, 1H, H5, J(H5,H4) = 7·7 Hz, J(H5, H6) = 7·5 Hz, J(H5,H7) = 1·1 Hz], 6·84 [ddd, 1H, H6, J(H6,H4) = 0·7 Hz, J(H6,H5) = 7·5 Hz, J(H6, H7) = 7·4 Hz], 6·99 [dd, 1H, H7, J(H7,H5) = 1·1 Hz, J(H7, H6) = 7·4 Hz], 7·25 [d, 1H, H5', J(H5', H6') = 9·1 Hz], 7·88 [d, 1H, H6', J(H6',H5') = 9·1 Hz], 8·79 [dd, 1H, H8', J(H8',H9') = 4·2 Hz, J(H8', H10') = 1·8 Hz], 7·43 [dd, 1H, H9', J(H9',H8') = 4·2 Hz, J(H9',H10') = 8·5 Hz], 8·86 [dd, 1H, H10', J(H10',H8') = 1·8 Hz, J(H10',H9') = 8·5 Hz]; ^{13}C{^{1}H} (CDCl$_3$) δ 24·2 (Me), 24·5 (Me), 25·8 (2'-Me), 30·2 (N-Me), 103·3 (C2/3'), 52·3 (C3), 119·4 (C4), 121·4 (C5), 128·1 (C6), 106·4 (C7), 135·3 (C4a), 144·2 (C7a), 160·6 (C2'), 120·0 (C5'), 130·2 (C6'), 148·4 (C8'), 121·5 (C9'), 130·3 (C10'), 125·5 (C1a'), 148·2 (C4a'), 144·5 (C6a'), 124·3 C(10a'). Mass spectra, m/e 343 (P); HRMS calc. for C$_{22}$H$_{21}$N$_3$O$^+$ 343·16791; found 343·16834.
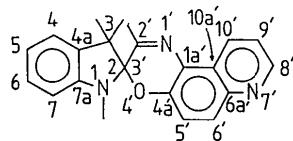
(4): This was prepared in a manner analogous to that for (2) but using 5-methoxy-1,3,3-trimethyloxindole. Purification of the final product was effected by flash chromatography (SiO$_2$, 230–400 mesh, 2:2:1 CHCl$_3$, hexane, ethanol). X-ray quality crystals were grown as for (2). Spectroscopic data for (4): NMR, ^{1}H (CDCl$_3$) δ 1·18 (s, 3H, Me), 1·25 (s, 3H, Me), 2·35 (s, 3H, 2'-Me), 2·87 (s, 3H, N-Me), 3·76 (s, 3H, O-Me), 6·62 [d, 1H, H4, J(H4,H6) = 2·2 Hz], 6·75 [dd, 1H, H6, J(H6,H4) = 2·2 Hz, J(H6,H7) = 8·2 Hz], 6·47 [d, 1H, H7, J(H7,H6) = 8·2 Hz], 7·24 [d, 1H, H5', J(H5',H6') = 9 Hz], 7·87 [d, 1H, H6', J(H6',H5') = 9 Hz], 8·85 (m, 2H, H8', H10'), 7·40 [dd, 1H, H9', J(H9',H8') and J(H9',H10') = 4·4 and 8·4 Hz]; ^{13}C{^{1}H} (CDCl$_3$) δ 23·7 (Me), 24·7 (Me), 25·9 (2'-Me), 30·7 (N-Me), 55·9 (O-Me), 103·7 (C2/3'), 52·6 (C3), 109·6 (C4), 154·1 (C5), 111·9 (C6), 106·7 (C7), 136·9 (C4a), 144·4 (C7a), 160·6 (C2'), 120·0 (C5'), 130·2 (C6'), 148·4 (C8'), 121·5 (C9'), 130·4 (C10'), 125·5 (C1a'), 142·5 (C4a'), 144·5 C(6a'), 124·3 (C10a'). Mass spectra, m/e 373 (P); HRMS calc. for C$_{23}$H$_{23}$N$_3$O$_2^+$ 373·17848; found 373·17889.
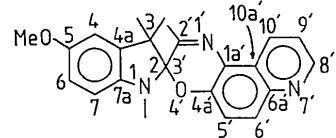
(5): This compound has been previously described (Simkin, Makarov, Furmanova, Karaev & Minkin, 1984).

(6): Ethyllithium (20 cm^3 of a 1·4 M solution in benzene) was added to a 100 cm^3 flask and cooled to 273 K. To this, a 1 M solution of 1,3,3-trimethyloxindole (17·3 g, 10·7 mmol) in diethyl ether was added at a rate such that the reaction temperature remained below 283 K. The flask was then allowed to warm to room temperature and was refluxed for 1 h. After this time, the flask was allowed to cool and excess ethyllithium was quenched by dropwise addition of water. The solution was washed with saturated NaCl, dried (K$_2$CO$_3$), filtered and the solvent removed under reduced pressure. The crude 2-ethylidene-1,3,3-trimethylindoline was then redissolved in ethanol and 5-nitrosalicylaldehyde (0·5 g, 3·0 mmol) was added. The resulting mixture was refluxed for 4 h and then allowed to cool, which resulted in the precipitation of (6) (0·61 g, 1·8 mmol, 60%) as microcrystals (m.p. 425–427 K). X-ray quality crystals were obtained by slow evaporation of an acetone solution. Spectroscopic data for (6): NMR, ^{1}H (CDCl$_3$), δ 1·18 (s, 3H, Me), 1·20 (s, 3H, Me), 2·02 [d, 3H, 3-Me, J(H4,Me) = 1 Hz], 2·85 (s, 3H, N-Me), 6·4–7·2 and 7·6–7·8 (m, 8H, H4, H5, H7, H8, H4', H5', H6', H7'); ^{13}C{^{1}H} (CDCl$_3$), δ 20·6 (Me), 22·3

(Me), 26·6 (3-Me), 29·9 (N-Me), 110·6 (C2/2'), 121·3 (C3), 121·4 (C4), 160·1 (C6), 124·9, 125·8, 127·8 (C5, C7, C8), 131·2 (C4a), 148·5 (C8a), 54·4 (C3'), 115·0 (C4'), 119·5 (C5'), 121·3 (C6'), 106·9 (C7'), 135·8 (C4a'), 141·2 (C7a'). Mass spectra, m/e 336 (P); HRMS calc. for $C_{20}H_{20}N_2O_3^+$ 336·14684; found 336·14727.
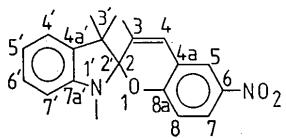
Crystallography. Data for compounds (2)–(6) are given in parentheses where they differ from those for (1). Crystal size 0·21 × 0·37 × 0·52 (0·13 × 0·30 × 0·50, 0·15 × 0·30 × 0·30, 0·10 × 0·25 × 0·50, 0·27 × 0·27 × 0·58, 0·25 × 0·50 × 0·60) mm; Stoe-Siemens diffractometer; unit-cell parameters from 2θ values of 32 reflections (30–40°) measured at $\pm\omega$. Data collection in ω/θ scan mode, scan range 0·680 [0·425, 0·468, 0·425, 0·510, 0·770]° below α_1 and above α_2, scan time 14–56 s; $2\theta_{max}$ 130 (130, 115, 115, 130, 130)°; index ranges $h - 12 \rightarrow 1$, $k\ 0 \rightarrow 17$, $l - 25 \rightarrow 25$, ($h - 8 \rightarrow 0$, $k\ 0 \rightarrow 26$, $l - 12 \rightarrow 12$; $h\ 0 \rightarrow 12$, $k - 11 \rightarrow 0$, $l - 17 \rightarrow 17$; $h - 10 \rightarrow 0$, $k\ 0 \rightarrow 18$, $l - 26 \rightarrow 26$; $h\ 0 \rightarrow 18$, $k - 12 \rightarrow 2$, $l - 23 \rightarrow 23$; $h - 14 \rightarrow 1$, $k\ 0 \rightarrow 15$, $l\ 0 \rightarrow 24$); no significant variation in intensities of three standard reflections, no absorption corrections; 6422 (2994, 2743, 5563, 6580, 2992) reflections measured, 5551 (2994, 2595, 5357, 5364, 2925) unique, 3999 (2574, 2091, 3241, 4265, 2048) with $F > 4\sigma_c(F)$ (σ_c from counting statistics only) and $R_{int} = 0·039$ (0, 0·024, 0·027, 0·035, 0·031).

Structure solution by direct methods, blocked-cascade least-squares refinement on F, weighting $w^{-1} = \sigma^2(F) = \sigma_c^2(F) + A_1 + A_2G + A_3G^2 + A_4H + A_5H^2 + A_6GH$ [$G = F_o/F_{max}$, $H = \sin\theta/\sin\theta_{max}$ (Wang & Robertson, 1985)] with parameters $A_1,...,A_6$ 6, −50, 219, −10, 6, 37 (−1, 12, 48, 4, −3, −32; 7, −31, 198, −15, 8, 11; 29, −387, 873, −56, 28, 386; 0, 0, 677, 0, 0, 0; 3, −3, 200, −8, 6, 5); anisotropic thermal parameters for all non-H atoms, H atoms constrained [C—H 0·96 Å, H—C—H 109·5°, aromatic and olefinic H on angle external bisectors, U(H) = 1·2U_{eq}(C)], extinction parameter $x = 2·8$ (4) × 10^{-6} [2·6 (3) × 10^{-5}, 6·8 (12) × 10^{-6}, 6·0 (3) × 10^{-6}, 7·0 (13) × 10^{-6}, 2·3 (3) × 10^{-6}], where $F'_c = F_c/(1 + xF_c^2/\sin2\theta)^{1/4}$. $R = 0·064$ (0·043, 0·061, 0·062, 0·054, 0·047), $wR = 0·071$ (0·035, 0·061, 0·036, 0·084, 0·059), $S = 1·05$ (1·37, 1·02, 1·35, 1·66, 1·04) for 496 (248, 257, 536, 452, 239) parameters; mean $\Delta/\sigma = 0·007$ (0·009, 0·006, 0·019, 0·031, 0·002), max. $\Delta/\sigma = 0·027$ (0·052, 0·022, 0·074, 0·131, 0·016); $(\Delta\rho)_{max} = 0·41$ (0·18, 0·37, 0·17, 0·24, 0·18), $(\Delta\rho)_{min} = -0·22$ (−0·27, −0·22, −0·22, −0·21, −0·16) e Å^{-3}. In the

structure of (1), some disorder was found for the NMe and CMe₂ groups of the indoline ring, such that these two are exchanged in a proportion of the molecules. The disorder was modelled by refinement of site occupancy factors for the relevant methyl groups, but normal scattering factors were used for the ring N and C atoms. The final occupancy factors for the major component of disorder of each of the two independent molecules were 0·834 (5) and 0·816 (5). Scattering factors were from *International Tables for X-ray Crystallography* (1974, Vol. IV, pp. 99, 149); *SHELXTL* (Sheldrick, 1985) and local computer programs were used.

Atomic coordinates and equivalent isotropic thermal parameters are given in Table 1, selected bond lengths and angles around the spiro carbon atoms in Table 2.*

Discussion. The structures presented here can be grouped as three pairs: (1) and (2), (3) and (4), (5) and (6) and the molecular structures are shown in Figs. 1, 2, 4, 5, 7 and 8 respectively. Figs. 3, 6 and 9 are least-squares-fit superpositions of the indoline residues of each respective pair of structures (with r.m.s. deviations for the fitted atoms of 0·04–0·05 Å in each case) and illustrate the extent of the distortion caused by the presence of the extra methyl group in (2), (4) and (6).

The main effect of the addition of the methyl group is on the oxazine or pyran ring, with only minor disturbance to the indoline ring system in each case. Table 3 gives selected mean-plane data on the degree of ring folding. Within the indoline ring, the spiro carbon atom lies out of the plane of the other four atoms and the degree of this envelope folding is similar in all the structures, with a slightly but significantly greater folding in the methyl derivatives. The increased folding of the oxazine ring on methyl substitution is much more marked, with the spiro carbon atom displaced further from the mean plane of the other five atoms. The significant difference between the two independent molecules of (5) in this respect indicates the extent to which the conformation is affected by crystal packing, but the intramolecular steric effect of the methyl group in the pairs of compounds (3)/(4) and (5)/(6) is still quite marked. This is less clear for the pair of compounds (1)/(2), where the oxazine ring is almost as folded in the unsubstituted compound, but to the opposite side; the situation here, however, is complicated by

Table 1. *Atomic coordinates* ($\times 10^4$) *and equivalent isotropic thermal parameters* ($\text{Å}^2 \times 10^3$) *for* (1), (2), (3), (4), (5) *and* (6)

U_{eq} is defined as one third of the trace of the orthogonalized U_{ij} tensor.

	x	y	z	U_{eq}
(1)				
O(1a)	2070 (2)	2536 (1)	1744 (1)	59 (1)
C(2a)	2184 (3)	3337 (2)	1451 (1)	49 (1)
C(3a)	3354 (3)	3569 (2)	1304 (1)	53 (1)
C(4a)	3508 (3)	4351 (2)	1002 (1)	56 (1)
C(5a)	2520 (3)	4938 (2)	840 (1)	50 (1)
N(6a)	2723 (2)	5700 (2)	515 (1)	67 (1)
C(7a)	1792 (3)	6243 (2)	385 (2)	76 (1)
C(8a)	622 (3)	6104 (2)	549 (2)	66 (1)
C(9a)	406 (3)	5343 (2)	861 (1)	56 (1)
C(10a)	1356 (3)	4726 (2)	1013 (1)	47 (1)
C(11a)	1209 (3)	3903 (2)	1329 (1)	51 (1)
N(12a)	64 (2)	3704 (2)	1525 (1)	70 (1)
C(13a)	−77 (3)	2904 (2)	1708 (2)	74 (1)
C(14a)	833 (3)	2160 (2)	1703 (1)	56 (1)
N(15a)	575 (3)	1616 (2)	1142 (1)	67 (1)
C(16a)	1045 (3)	752 (2)	1281 (1)	57 (1)
C(17a)	1276 (3)	70 (3)	880 (2)	81 (2)
C(18a)	1680 (4)	−728 (3)	1147 (3)	102 (2)
C(19a)	1850 (4)	−856 (3)	1779 (3)	107 (2)
C(20a)	1631 (4)	−161 (3)	2181 (2)	82 (2)
C(21a)	1235 (3)	643 (2)	1928 (1)	57 (1)
C(22a)	873 (3)	1471 (2)	2243 (1)	58 (1)
C(23a)	1719 (5)	1732 (3)	2839 (2)	102 (2)
C(24a)	−404 (4)	1321 (3)	2460 (2)	71 (2)
C(25a)	529 (6)	2006 (3)	523 (2)	117 (2)
C(25x)	−699 (35)	1489 (23)	769 (19)	167 (16)
O(1b)	7037 (2)	10249 (1)	1621 (1)	60 (1)
C(2b)	7174 (3)	9408 (2)	1387 (1)	49 (1)
C(3b)	8358 (3)	9150 (2)	1291 (1)	54 (1)
C(4b)	8547 (3)	8322 (2)	1065 (1)	56 (1)
C(5b)	7571 (3)	7714 (2)	926 (1)	50 (1)
N(6b)	7821 (3)	6892 (2)	697 (1)	63 (1)
C(7b)	6907 (3)	6334 (2)	576 (2)	67 (1)
C(8b)	5695 (3)	6523 (2)	665 (1)	61 (1)
C(9b)	5435 (3)	7342 (2)	892 (1)	55 (1)
C(10b)	6383 (3)	7972 (2)	1034 (1)	47 (1)
C(11b)	6195 (3)	8840 (2)	1270 (1)	49 (1)
N(12b)	5022 (2)	9080 (2)	1410 (1)	64 (1)
C(13b)	4876 (3)	9895 (2)	1551 (2)	69 (1)
C(14b)	5801 (3)	10629 (2)	1551 (1)	56 (1)
N(15b)	5759 (3)	11243 (2)	2071 (1)	69 (1)
C(16b)	6151 (3)	12086 (2)	1889 (1)	55 (1)
C(17b)	6521 (4)	12824 (2)	2251 (1)	73 (1)
C(18b)	6812 (4)	13593 (2)	1950 (2)	81 (2)
C(19b)	6752 (3)	13636 (2)	1313 (2)	77 (2)
C(20b)	6394 (3)	12894 (2)	946 (2)	66 (1)
C(21b)	6088 (3)	12120 (2)	1237 (1)	55 (1)
C(22b)	5617 (3)	11248 (2)	968 (2)	60 (1)
C(23b)	6276 (5)	10925 (3)	412 (2)	97 (2)
C(24b)	4248 (4)	11352 (3)	700 (2)	73 (2)
C(25b)	6073 (6)	10928 (3)	2710 (2)	122 (3)
C(25y)	4530 (21)	11352 (15)	2432 (12)	89 (9)
(2)				
O(1)	7893 (1)	8987 (1)	7585 (1)	46 (1)
C(2)	7540 (2)	9540 (1)	7098 (1)	41 (1)
C(3)	9015 (2)	9867 (1)	6714 (1)	52 (1)
C(4)	8727 (2)	10433 (1)	6269 (2)	57 (1)
C(5)	6959 (2)	10692 (1)	6179 (1)	45 (1)
N(6)	6778 (2)	11274 (1)	5799 (1)	57 (1)
C(7)	5106 (3)	11493 (1)	5682 (1)	58 (1)
C(8)	3530 (2)	11170 (1)	5877 (2)	57 (1)
C(9)	3694 (2)	10593 (1)	6283 (1)	50 (1)
C(10)	5461 (2)	10340 (1)	6485 (1)	39 (1)
C(11)	5774 (2)	9755 (1)	6969 (1)	38 (1)
N(12)	4280 (1)	9391 (1)	7218 (1)	43 (1)
C(13)	4608 (2)	8901 (1)	7810 (1)	42 (1)
C(14)	6533 (2)	8729 (1)	8344 (1)	39 (1)
N(15)	6905 (2)	8095 (1)	8360 (1)	43 (1)
C(16)	8386 (2)	7999 (1)	9241 (1)	41 (1)
C(17)	9614 (2)	7523 (1)	9337 (1)	51 (1)
C(18)	10963 (2)	7525 (1)	10316 (2)	59 (1)
C(19)	11106 (2)	7984 (1)	11148 (2)	60 (1)
C(20)	9881 (2)	8467 (1)	11028 (1)	54 (1)
C(21)	8538 (2)	8470 (1)	10073 (1)	43 (1)
C(22)	7019 (2)	8918 (1)	9725 (1)	42 (1)
C(23)	3008 (2)	8491 (1)	7971 (2)	60 (1)

Table 1 (*cont.*)

	x	y	z	U_{eq}
C(24)	6821 (3)	7771 (1)	7208 (1)	61 (1)
C(25)	5397 (3)	8789 (1)	10494 (2)	58 (1)
C(26)	7619 (3)	9568 (1)	9889 (2)	61 (1)
(3)				
O(1)	7718 (3)	6893 (2)	3549 (1)	74 (1)
C(2)	7576 (3)	7028 (3)	4353 (2)	50 (1)
C(3)	7506 (3)	8257 (3)	4642 (2)	49 (1)
C(4)	7401 (3)	8454 (3)	5448 (2)	52 (1)
C(5)	7342 (3)	7449 (3)	6001 (2)	46 (1)
N(6)	7230 (3)	7701 (3)	6805 (2)	63 (1)
C(7)	7186 (4)	6741 (4)	7303 (2)	68 (1)
C(8)	7251 (3)	5501 (3)	7071 (2)	57 (1)
C(9)	7356 (3)	5230 (3)	6276 (2)	51 (1)
C(10)	7409 (3)	6217 (3)	5708 (2)	43 (1)
C(11)	7553 (3)	6024 (3)	4871 (2)	51 (1)
N(12)	7699 (3)	4791 (2)	4609 (2)	69 (1)
C(13)	7812 (4)	4648 (3)	3857 (2)	73 (2)
C(14)	7740 (4)	5648 (3)	3175 (2)	59 (1)
N(15)	6631 (3)	5478 (3)	2452 (2)	62 (1)
C(16)	6854 (3)	5930 (3)	1692 (2)	48 (1)
C(17)	6000 (3)	6164 (3)	882 (2)	58 (1)
C(18)	6442 (3)	6523 (3)	207 (2)	56 (1)
C(19)	7687 (3)	6642 (3)	340 (2)	51 (1)
C(20)	8516 (3)	6414 (3)	1148 (2)	51 (1)
C(21)	8081 (3)	6046 (2)	1831 (2)	46 (1)
C(22)	8765 (3)	5645 (3)	2743 (2)	55 (1)
O(23)	7987 (2)	6965 (2)	−396 (1)	67 (1)
C(24)	9217 (4)	7175 (6)	−303 (3)	105 (2)
C(25)	5451 (4)	5582 (5)	2584 (3)	88 (2)
C(26)	9838 (4)	6509 (4)	3194 (2)	72 (1)
C(27)	9269 (4)	4313 (3)	2711 (2)	65 (1)
(4)				
O(1a)	3297 (2)	8951 (1)	1566 (1)	47 (1)
C(2a)	4204 (3)	8481 (2)	1348 (1)	44 (1)
C(3a)	4887 (3)	8819 (2)	947 (1)	49 (1)
C(4a)	5771 (3)	8365 (2)	701 (1)	51 (1)
C(5a)	6009 (3)	7560 (2)	856 (1)	42 (1)
N(6a)	6898 (3)	7134 (2)	596 (1)	53 (1)
C(7a)	7136 (3)	6385 (2)	758 (1)	59 (2)
C(8a)	6534 (3)	6016 (2)	1162 (1)	61 (2)
C(9a)	5633 (3)	6423 (2)	1426 (1)	53 (2)
C(10a)	5338 (3)	7230 (2)	1279 (1)	43 (1)
C(11a)	4450 (3)	7714 (2)	1537 (1)	43 (1)
N(12a)	3980 (2)	7439 (2)	2016 (1)	54 (1)
C(13a)	3069 (3)	7857 (2)	2203 (1)	50 (1)
C(14a)	2315 (3)	8540 (2)	1861 (1)	45 (1)
N(15a)	1798 (2)	9141 (1)	2195 (1)	46 (1)
C(16a)	689 (3)	9531 (2)	1838 (1)	45 (1)
C(17a)	89 (3)	10263 (2)	1894 (1)	54 (1)
C(18a)	−1027 (3)	10497 (2)	1482 (1)	53 (1)
C(19a)	−1529 (3)	9993 (2)	1044 (1)	54 (2)
C(20a)	−920 (3)	9259 (2)	987 (1)	49 (1)
C(21a)	173 (3)	9036 (2)	1384 (1)	41 (1)
C(22a)	1004 (3)	8281 (2)	1422 (1)	41 (1)
O(23a)	−2613 (2)	10175 (1)	617 (1)	74 (1)
C(24a)	−3240 (4)	10923 (2)	619 (2)	90 (2)
C(25a)	2756 (4)	9628 (2)	2582 (1)	70 (2)
C(26a)	1304 (3)	8012 (2)	847 (1)	59 (2)
C(27a)	230 (3)	7614 (2)	1678 (1)	65 (2)
C(28a)	2727 (4)	7642 (2)	2764 (1)	70 (2)
O(1b)	1998 (2)	7303 (1)	8634 (1)	52 (1)
C(2b)	1099 (3)	6842 (2)	8866 (1)	47 (1)
C(3b)	407 (3)	7200 (2)	9262 (1)	60 (2)
C(4b)	−473 (3)	6766 (2)	9512 (1)	58 (2)
C(5b)	−714 (3)	5951 (2)	9373 (1)	51 (1)
N(6b)	−1600 (3)	5545 (2)	9647 (1)	63 (1)
C(7b)	−1818 (4)	4795 (3)	9503 (1)	71 (2)
C(8b)	−1236 (4)	4406 (2)	9097 (1)	71 (2)
C(9b)	−367 (3)	4801 (2)	8821 (1)	56 (2)
C(10b)	−66 (3)	5601 (2)	8958 (1)	43 (1)
C(11b)	836 (3)	6061 (2)	8699 (1)	43 (1)
N(12b)	1353 (2)	5761 (1)	8231 (1)	50 (1)
C(13b)	2269 (3)	6154 (2)	8040 (1)	51 (1)
C(14b)	2994 (3)	6874 (2)	8356 (1)	49 (1)
N(15b)	3481 (2)	7445 (2)	7995 (1)	52 (1)
C(16b)	4551 (3)	7893 (2)	8323 (1)	45 (1)
C(17b)	5119 (3)	8606 (2)	8221 (1)	54 (1)
C(18b)	6205 (3)	8916 (2)	8616 (1)	54 (1)
C(19b)	6703 (3)	8496 (2)	9095 (1)	51 (1)
C(20b)	6144 (3)	7748 (2)	9198 (1)	49 (1)
C(21b)	5078 (3)	7456 (2)	8810 (1)	46 (1)
C(22b)	4313 (3)	6670 (2)	8801 (1)	45 (1)

Table 1 (cont.)

	x	y	z	U_{eq}
O(23b)	7754 (2)	8736 (1)	9515 (1)	70 (1)
C(24b)	8410 (4)	9459 (2)	9428 (2)	82 (2)
C(25b)	2510 (4)	7868 (2)	7571 (1)	71 (2)
C(26b)	4048 (3)	6422 (2)	9378 (1)	65 (2)
C(27b)	5182 (4)	6036 (2)	8564 (2)	66 (2)
C(28b)	2653 (4)	5879 (3)	7500 (1)	83 (2)
(5)				
O(1a)	2973 (1)	3353 (1)	4548 (1)	73 (1)
C(2a)	3354 (1)	3153 (2)	4027 (1)	54 (1)
C(3a)	3446 (1)	1947 (2)	3843 (1)	61 (1)
C(4a)	3841 (1)	1687 (2)	3321 (1)	57 (1)
C(5a)	4143 (1)	2639 (2)	2995 (1)	50 (1)
C(6a)	4046 (1)	3835 (2)	3167 (1)	54 (1)
C(7a)	3650 (1)	4115 (2)	3687 (1)	56 (1)
C(8a)	3510 (2)	5339 (2)	3889 (1)	74 (1)
C(9a)	3149 (2)	5556 (2)	4406 (1)	77 (1)
C(10a)	2845 (1)	4587 (2)	4804 (1)	56 (1)
N(11a)	1939 (1)	4689 (2)	4750 (1)	59 (1)
C(12a)	1782 (1)	4243 (2)	5366 (1)	48 (1)
C(13a)	998 (1)	3947 (2)	5488 (1)	65 (1)
C(14a)	1003 (2)	3603 (2)	6161 (1)	78 (1)
C(15a)	1735 (2)	3547 (2)	6687 (1)	80 (1)
C(16a)	2520 (2)	3818 (2)	6565 (2)	71 (1)
C(17a)	2540 (1)	4163 (2)	5891 (1)	51 (1)
C(18a)	3275 (1)	4594 (2)	5618 (1)	61 (1)
N(19a)	4588 (1)	2371 (2)	2466 (1)	59 (1)
O(20a)	4918 (1)	3205 (2)	2225 (1)	88 (1)
O(21a)	4632 (1)	1320 (2)	2284 (1)	89 (1)
C(22a)	1312 (2)	4542 (3)	4074 (1)	104 (1)
C(23a)	4070 (2)	3760 (3)	5831 (2)	104 (1)
C(24a)	3533 (2)	5890 (3)	5896 (2)	87 (1)
O(1b)	2918 (1)	3369 (1)	9036 (1)	56 (1)
C(2b)	3502 (1)	3162 (2)	8672 (1)	47 (1)
C(3b)	3652 (1)	1965 (2)	8517 (1)	56 (1)
C(4b)	4242 (1)	1707 (2)	8147 (1)	54 (1)
C(5b)	4683 (1)	2667 (2)	7939 (1)	47 (1)
C(6b)	4519 (1)	3860 (2)	8075 (1)	49 (1)
C(7b)	3925 (1)	4128 (2)	8437 (1)	48 (1)
C(8b)	3671 (2)	5349 (2)	8554 (1)	60 (1)
C(9b)	3142 (2)	5563 (2)	8953 (1)	63 (1)
C(10b)	2823 (1)	4588 (2)	9340 (1)	51 (1)
N(11b)	1923 (1)	4708 (2)	9294 (1)	60 (1)
C(12b)	1767 (1)	4255 (2)	9912 (1)	55 (1)
C(13b)	989 (2)	3993 (2)	10056 (1)	73 (1)
C(14b)	1025 (2)	3645 (2)	10749 (2)	84 (1)
C(15b)	1772 (2)	3559 (2)	11258 (1)	80 (1)
C(16b)	2541 (2)	3799 (2)	11108 (1)	69 (1)
C(17b)	2535 (1)	4141 (2)	10434 (1)	52 (1)
C(18b)	3264 (1)	4554 (2)	10148 (1)	55 (1)
N(19b)	5320 (1)	2399 (2)	7562 (1)	58 (1)
O(20b)	5764 (1)	3236 (2)	7450 (1)	88 (1)
O(21b)	5395 (1)	1354 (2)	7379 (1)	86 (1)
C(22b)	1284 (2)	4623 (4)	8625 (1)	104 (1)
C(23b)	4046 (2)	3712 (3)	10341 (1)	83 (1)
C(24b)	3539 (2)	5837 (2)	10433 (1)	79 (1)
(6)				
O(1)	3352 (1)	6307 (1)	6473 (1)	51 (1)
C(2)	4348 (2)	6628 (2)	6530 (1)	47 (1)
C(3)	4538 (2)	7705 (2)	6544 (1)	53 (1)
C(4)	5548 (2)	8060 (2)	6585 (1)	55 (1)
C(5)	6339 (2)	7332 (2)	6615 (1)	52 (1)
C(6)	6157 (2)	6259 (2)	6621 (1)	54 (1)
C(7)	5145 (2)	5883 (2)	6582 (1)	52 (1)
C(8)	4856 (2)	4777 (2)	6624 (1)	62 (1)
C(9)	3894 (2)	4437 (2)	6518 (1)	58 (1)
C(10)	3097 (2)	5214 (2)	6269 (1)	48 (1)
N(11)	2062 (1)	5037 (1)	6505 (1)	50 (1)
C(12)	1369 (2)	5506 (2)	6079 (1)	48 (1)
C(13)	349 (2)	5805 (2)	6179 (1)	60 (1)
C(14)	−180 (2)	6254 (2)	5673 (1)	71 (1)
C(15)	279 (2)	6401 (2)	5103 (1)	77 (1)
C(16)	1303 (2)	6104 (2)	5008 (1)	68 (1)
C(17)	1843 (2)	5659 (2)	5501 (1)	50 (1)
C(18)	2942 (2)	5243 (2)	5533 (1)	54 (1)
N(19)	7404 (2)	7720 (2)	6641 (1)	62 (1)
O(20)	8099 (1)	7072 (2)	6716 (1)	92 (1)
O(21)	7560 (2)	8668 (2)	6580 (1)	86 (1)
C(22)	1875 (2)	5158 (2)	7177 (1)	69 (1)
C(23)	3721 (2)	5947 (3)	5187 (1)	70 (1)
C(24)	2964 (2)	4120 (2)	5248 (2)	73 (1)
C(25)	3580 (3)	3306 (2)	6640 (2)	82 (1)

Table 2. Selected bond lengths (Å) and angles (°)

(1)

C(14a)—O(1a)	1·464 (4)			C(14b)—O(1b)	1·465 (4)	
C(14a)—C(13a)	1·500 (5)			C(14b)—C(13b)	1·499 (5)	
C(14a)—N(15a)	1·447 (4)			C(14b)—N(15b)	1·447 (4)	
C(14a)—C(22a)	1·544 (5)			C(14b)—C(22b)	1·545 (5)	

O(1a)—C(14a)—C(13a)	109·2 (3)	O(1b)—C(14b)—C(13b)	109·6 (2)
O(1a)—C(14a)—N(15a)	110·5 (3)	O(1b)—C(14b)—N(15b)	106·8 (2)
C(13a)—C(14a)—N(15a)	111·4 (3)	C(13b)—C(14b)—N(15b)	112·4 (3)
O(1a)—C(14a)—C(22a)	105·9 (2)	O(1b)—C(14b)—C(22b)	109·9 (3)
C(13a)—C(14a)—C(22a)	116·6 (3)	C(13b)—C(14b)—C(22b)	114·8 (3)
N(15a)—C(14a)—C(22a)	103·1 (2)	N(15b)—C(14b)—C(22b)	102·9 (2)

(2)

C(14)—O(1)	1·467 (2)	C(14)—C(13)	1·526 (2)
C(14)—N(15)	1·442 (2)	C(14)—C(22)	1·580 (2)

O(1)—C(14)—C(13)	109·3 (1)	O(1)—C(14)—N(15)	104·9 (1)
C(13)—C(14)—N(15)	114·8 (1)	O(1)—C(14)—C(22)	109·2 (1)
C(13)—C(14)—C(22)	115·1 (1)	N(15)—C(14)—C(22)	102·9 (1)

(3)

C(14)—O(1)	1·467 (4)	C(14)—C(13)	1·517 (5)
C(14)—N(15)	1·449 (4)	C(14)—C(22)	1·544 (6)

O(1)—C(14)—C(13)	110·5 (3)	O(1)—C(14)—N(15)	108·7 (3)
C(13)—C(14)—N(15)	109·2 (3)	O(1)—C(14)—C(22)	107·4 (3)
C(13)—C(14)—C(22)	116·5 (3)	N(15)—C(14)—C(22)	104·2 (3)

(4)

C(14a)—O(1a)	1·474 (4)	C(14b)—O(1b)	1·475 (4)
C(14a)—C(13a)	1·523 (5)	C(14b)—C(13b)	1·533 (5)
C(14a)—N(15a)	1·437 (4)	C(14b)—N(15b)	1·433 (4)
C(14a)—C(22a)	1·583 (4)	C(14b)—C(22b)	1·573 (4)

O(1a)—C(14a)—C(13a)	107·8 (2)	O(1b)—C(14b)—C(13b)	108·3 (2)
O(1a)—C(14a)—N(15a)	106·0 (2)	O(1b)—C(14b)—N(15b)	105·9 (3)
C(13a)—C(14a)—N(15a)	114·5 (3)	C(13b)—C(14b)—N(15b)	113·8 (2)
O(1a)—C(14a)—C(22a)	110·0 (2)	O(1b)—C(14b)—C(22b)	110·0 (2)
C(13a)—C(14a)—C(22a)	114·8 (3)	C(13b)—C(14b)—C(22b)	115·3 (3)
N(15a)—C(14a)—C(22a)	103·4 (2)	N(15b)—C(14b)—C(22b)	103·1 (2)

(5)

C(10a)—O(1a)	1·481 (3)	C(10b)—O(1b)	1·491 (3)
C(10a)—C(9a)	1·483 (4)	C(10b)—C(9b)	1·486 (3)
C(10a)—N(11a)	1·441 (3)	C(10b)—N(11b)	1·438 (3)
C(10a)—C(18a)	1·565 (3)	C(10b)—C(18b)	1·560 (3)

O(1a)—C(10a)—C(9a)	112·2 (2)	O(1b)—C(10b)—C(9b)	110·7 (2)
O(1a)—C(10a)—N(11a)	106·2 (2)	O(1b)—C(10b)—N(11b)	105·6 (2)
C(9a)—C(10a)—N(11a)	112·4 (2)	C(9b)—C(10b)—N(11b)	112·8 (2)
O(1a)—C(10a)—C(18a)	106·9 (2)	O(1b)—C(10b)—C(18b)	108·7 (2)
C(9a)—C(10a)—C(18a)	114·9 (2)	C(9b)—C(10b)—C(18b)	114·6 (2)
N(11a)—C(10a)—C(18a)	103·5 (2)	N(11b)—C(10b)—C(18b)	103·7 (2)

(6)

C(10)—O(1)	1·481 (3)	C(10)—C(9)	1·516 (3)
C(10)—N(11)	1·446 (3)	C(10)—C(18)	1·576 (4)

O(1)—C(10)—C(9)	110·4 (2)	O(1)—C(10)—N(11)	104·3 (2)
C(9)—C(10)—N(11)	114·1 (2)	O(1)—C(10)—C(18)	107·2 (2)
C(9)—C(10)—C(18)	116·6 (2)	N(11)—C(10)—C(18)	103·2 (2)

Table 3. Mean plane distances (Å) and angles (°)

Molecule	R.m.s. Δ Plane 1	R.m.s. Δ Plane 4	Dihedral angle Planes 1–2	Dihedral angle Planes 3–4	Dihedral angle Planes 2–3
(1A)	0·001	0·054	27·9	27·8	86·4
(1B)	0·002	0·044	27·4	24·0	89·5
(2)	0·002	0·049	33·5	30·9	88·2
(3)	0·001	0·008	25·9	8·4	87·2
(4A)	0·009	0·043	30·2	35·4	88·3
(4B)	0·001	0·042	31·6	34·2	88·7
(5A)	0·002	0·010	24·8	2·1	89·6
(5B)	0·002	0·029	23·9	19·5	89·2
(6)	0·004	0·034	30·8	28·3	89·4

partial disorder of the indoline system, such that approximately 18% of the molecules have the NMe and the CMe_2 groups exchanged.
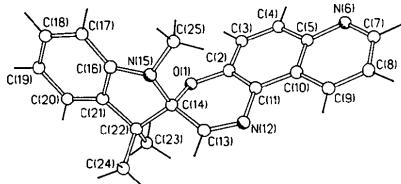

Fig. 1. The structure of molecule A of (1). The minor component of the disorder is not shown.
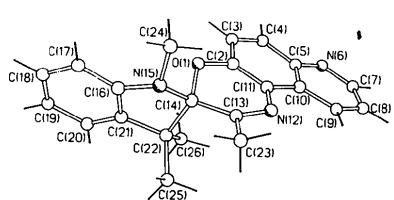

Fig. 2. The structure of (2).
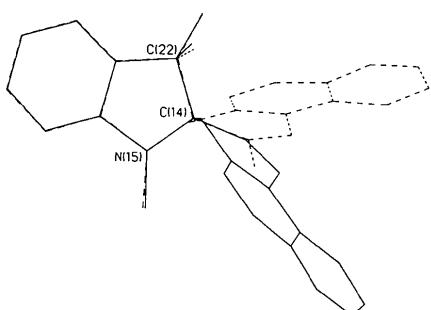
Fig. 3. Comparison of the structures of (1) (molecule A) and (2). The view for this figure and for Figs. 6 and 9 is normal to the indole ring in each case.
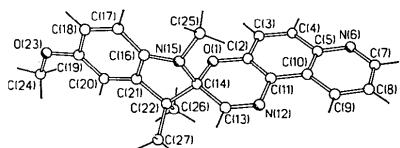

Fig. 4. The structure of (3).
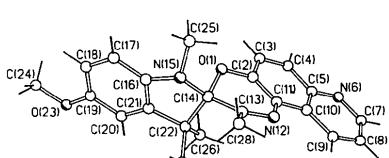
Fig. 5. The structure of molecule A of (4).

A secondary consequence of the ring folding in these structures on methyl substitution is a slight increase in the pyramidality of the indoline N atom, such that the sum of angles about this atom decreases by about 4–6°.

The data in Table 3 also show that the two rings joined at the spiro carbon atom remain mutually orthogonal in all structures.

MNDO geometry optimization of all these structures using the *MOPAC* program package (Stewart, 1988) successfully reproduces all of the above major structural effects, indicating that the role of crystal packing effects is probably secondary.

All of the structures described here are of the 'closed' colourless forms of the photochromic materials. Whilst the non-methyl-substituted compounds exhibit photochromic behaviour in the vis-
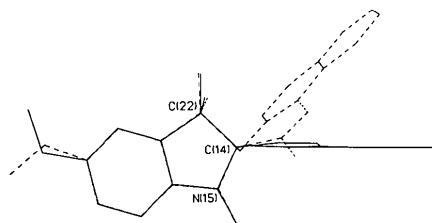
Fig. 6. Comparison of the structures of (3) and (4) (molecule A).
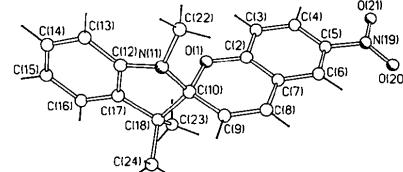
Fig. 7. The structure of molecule A of (5).
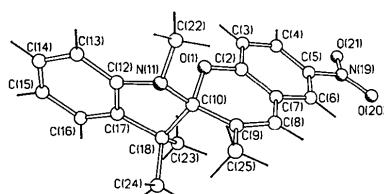

Fig. 8. The structure of (6).
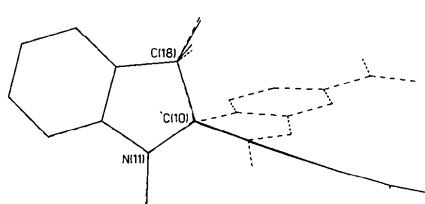
Fig. 9. Comparison of the structures of (5) (molecule A) and (6).

ible region of the electromagnetic spectrum, the methylated derivatives do not. Although these structures provide no direct information on the 'open' coloured forms of the compounds, an examination of molecular models indicates that the presence of the additional methyl group sterically hinders the formation of the 'open' planar geometry. Whether or not the open form is produced at all, or, if produced, whether it is non-planar and therefore colourless, is not clear, but is the subject of continuing study.

After completion of this work, we were made aware of a previous determination of the structure of (5) (Karaev, Furmanova & Belov, 1982). There are no significant differences between the two independent results in terms of the crystal and molecular structures observed, although they are reported with different unit-cell settings and choices of origin; the two determinations are of similar precision and the difference in the conformation of the two crystallographically independent molecules in the structure is seen clearly in the two sets of results.

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Huperzine A – a Potent Acetylcholinesterase Inhibitor of Use in the Treatment of Alzheimer's Disease

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Abstract. Huperzine A, 9-amino-13-ethylidene-11-methyl-4-azatricyclo[7.3.1.0³·⁸]trideca-3(8),6,11-trien-5-one, $C_{15}H_{18}N_2O$, $M_r = 242.32$, monoclinic, $P2_1/n$, $a = 8.8574$ (6), $b = 12.1833$ (7), $c = 12.4278$ (7) Å, $\beta = 99.956$ (5)°, $V = 1320.9$ (1) Å^3, $Z = 4$, $D_x = 1.22$ g cm^{-3}, λ(Cu $K\alpha$) = 1.54178 Å, $\mu = 5.75$ cm^{-1}, $F(000) = 520$, $T = 296$ K, $R_F = 6.30\%$ for 1402 reflections with $F_o \geq 5\sigma(F_o)$ and 183 parameters. The pyridone ring is planar and the stereochemistry of the C(11)—C(12) double bond is E.

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Introduction. Huperzine A (1) is a newly isolated alkaloid obtained from the clubmoss *Huperzia serrata* (Thunb.) Trev. = *Lycopodium serratum* Thunb., a Chinese folk medicine (Qian Ceng Ta) (Liu, Zhu, Yu, Zhou, Han, Wu & Qi, 1986). Huperzine A has attracted considerable interest among researchers because of its potent acetylcholinesterase (AChE) inhibitory activity (Wang, Yue & Tang, 1986). The compound has now been used clinically in China in the treatment of individuals suffering from various forms of memory impairment including Alzheimer's dementia (Zhang, 1986). While the structure of this compound was determined by spec-