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Azolides

VII—Restricted Rotation in *N*-Acylindoles and Carbazoles. Anisotropy Effect of the Carbonyl Group

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Abstract—The barrier to internal rotation about the N—C bond and the E/Z configuration of some *N*-acetyl and *N*-formylindole derivatives have been determined and discussed in terms of electronic and steric effects. The barriers to internal rotation have been determined for certain *N*-acetylcarbazoles and some new *N*-formyl derivatives of carbazole. Experimental proof is also given, showing that contrary to the provisions of the classical model of carbonyl anisotropy, the protons (α and *peri* positions) next to the oxygen of the acyl group are displaced to high frequencies. This result allows one to determine the preferred configuration of *N*-acetyl derivatives of perimidine and 1H-naphtho[1,8-de]triazine.

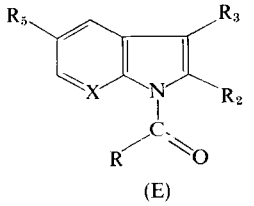
INTRODUCTION

THIS work follows from our research into the NMR spectroscopic properties of acyl derivatives of azoles: pyrrole,[1,2] imidazole,[1–3] pyrazole,[1,2,4] *s*-triazole,[1,2] *v*-triazole,[1,2] tetrazole,[1,2] benzimidazole,[1,5,6] indazole[1,7–9]§ and benzotriazole.§ These papers dealt with two problems: the determination of the E/Z‖ configuration from the mean chemical shifts of the equilibrium mixtures[1,2,6,§] and of the barrier to internal rotation about the C—N joining the heterocycle to the acetyl group.[2,3]

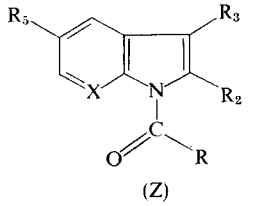
The present paper discusses a dynamic NMR study of *N*-formyl and *N*-acetylindoles and carbazoles. Three factors can influence the preferred configuration and rotational barrier in such molecules: (a) the coplanarity of the *N*-acyl group with the heteroaromatic system; (b) the dipole–dipole interaction between the carbonyl group and the π-system or the heteroatom in position 7 (in the case of 7-azaindole); (c) the steric interaction of substituents in positions 2 and 7 of indole or 1 and 8 of carbazole with the acyl group.

Barriers to internal rotation

N-*acylindoles*



(E)



(Z)

(a) R = H; (b) R = CH_3

	R_2	R_3	R_5	X		R_2	R_3	R_5	X
(1)	H	H	H	CH	(4)	CH_3	CH_3	H	CH
(2)	H	H	OCH_3	CH	(5)	H	H	H	N
(3)	H	CH_3	H	CH					

The NMR data concerning the E and Z rotamers are described in Tables 1 and 2, respectively: the values of the barriers to internal rotation are given in Table 3, together with the population of the rotamers where both configurations are observed.

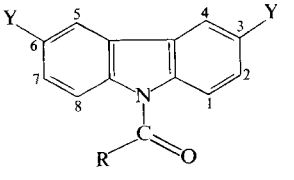
Distinct configurations have never been observed in the *N*-acetyl **b** series, even at low temperatures (**1b** and **2b** in THF (tetrahydrofuran) at −90 °C, **4b** in d_6-acetone at −90 °C). This may be due either to an immense lowering of the rotational barrier preventing both rotamers from being observed under our experimental conditions, or to the existence of a very favoured rotamer (more than 90%). The first hypothesis can be ruled out because the lowering of the barrier, expected when an acetyl group is involved instead of a formyl group, has never been described as important. (For a discussion of the barriers in 2-formyl and 2-acetylfuran see Ref. 11.) In the case of pyrrole, for example, the difference is about 4 kJ mol^{-1} [2,12] and even for carbazole (see later) in which steric hindrance plays an important role along with the electronic interaction the difference is about 20 kJ mol^{-1}. Therefore, it is the second hypothesis which is true. Later we will discuss the E/Z configuration of the preferred rotamer of acetylindoles.

For *N*-formylindoles we have been able to determine the barrier for the derivatives **1a**, **3a** and **4a** (Table 3), but not for *N*-formyl-7-azaindole (**5a**) for which the E form greatly predominates.

The higher barrier found for **3a** compared with **1a** can be explained by the donor effect of the methyl group in position 3. For *N*-formyl-2,3-dimethylindole (**4a**), the lowering of the barrier is due to the steric interaction of the additional methyl group in position 2 with the carbonyl of the formyl group, making the planar state E unfavourable.

Compared with *N*-formylpyrrole,[12] indoles show a higher barrier due to fusion of a conjugated ring. This has also been observed when comparing *N*-benzoylimidazole with *N*-benzoylbenzimidazole.[13]

N-*acylcarbazoles*



(6) Y = H
(7) Y = Br

(a) R = H; (b) R = CH_3

We have also studied the rotational barrier in *N*-acylcarbazoles (**6** and **7**). NMR data‡ and rotational

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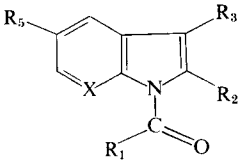
§ J. Elguero, L. Pappalardo and M. C. Pardo, unpublished results.

‖ As in our recent work on azoles[2,10]¶ we have adopted the E/Z nomenclature for simplicity. A designation of the form E is understood as the rotamer closest to the planar form of configuration E. This does not allude to the value of the dihedral angle θ (formed by the planes of the heterocycle and the acyl group), since, except where θ = 90°, the rotamer of minimum energy will always be nearer one configuration than the other.

¶ J. P. Fayet, P. Mauret, M. C. Vertut, R. M. Claramunt and J. Elguero, unpublished results.

‡ Compounds **6b** and **7b** have been described and their NMR spectra recorded without any assignments.[14]

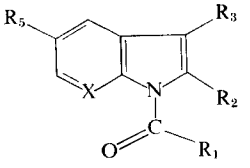
TABLE 1. CHEMICAL SHIFTS AND COUPLING CONSTANTS OF INDOLES IN THE E CONFIGURATION



No.	R_1	R_2	R_3	R_5	X	Solvent T °C	R_2	R_3	H-4	R_5	H-6	H-7	R_1
(1a)	H	H	H	H	CH	$CDCl_3$ −21[a]	7·75	6·72				7·3–7·4	9·38 $J_{13} \neq 0$
(3a)	H	H	CH_3	H	CH	$CDCl_3$ −21[a]		2·21				7·3–7·4	9·13[c]
(4a)	H	CH_3	CH_3	H	CH	$CDCl_3$ −20[b]						7·3–7·5	9·48
(5a)	H	H	H	H	N	$CDCl_3$ 27[a]	7·81 $J_{23} = 4·0$ $J_{26} \neq 0$	6·65	7·89 $J_{45} = 7·8$ $J_{46} = 1·7$	7·24	8·41 $J_{56} = 4·8$	—	9·80 $J_{12} \neq 0$ $J_{13} = 1·2$ $J_{14} = 0·3$
(4b)	CH_3	CH_3	CH_3	H	CH	Acetone-d_6 31[b]	2·52	2·17				7·95	2·66
(5b)	CH_3	H	H	H	N	$CDCl_3$ 27[a]	7·96 $J_{23} = 4·2$ $J_{26} = 1·8$	6·55	7·84 $J_{45} = 7·8$ $J_{46} = 1·7$	7·15	8·34 $J_{56} = 4·8$	—	3·02

[a] 100 MHz.
[b] 60 MHz.
[c] In $CDCl_3$ at 27 °C (100 MHz) δ(H-1): 9·06 ppm.

TABLE 2. CHEMICAL SHIFTS AND COUPLING CONSTANTS OF INDOLES IN THE Z CONFIGURATION



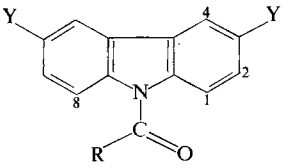
No.	R_1	R_2	R_3	R_5	Solvent T °C	R_2	R_3	H-4	R_5	H-6	H-7	R_1
(1a)	H	H	H	H	$CDCl_3$ −21[b]		6·68				8·41	9·04
(3a)	H	H	CH_3	H	CCl_4 27[b]	6·85[d]	2·21				8·36[d]	8·80[d]
(4a)	H	CH_3	CH_3	H	$CDCl_3$ −20[c]	2·43	2·73				8·37	9·11
(1b)	CH_3	H	H	H	$CDCl_3$ 27[b]	7·27 $J_{23} = 3·8$	6·52 $J_{37} = 0·8$	7·49			8·37	2·36
(2b)	CH_3	H	H	OCH_3	$CDCl_3$ 27[b]	7·32 $J_{23} = 3·8$ $J_{26} = 0·5$	6·51 $J_{37} = 0·8$	6·98 $J_{46} = 2·4$ $J_{47} = 0·6$ $J_{45} \neq 0$	3·81	6·94	8·31 $J_{67} = 8·7$	2·54
(3b)	CH_3	H	CH_3	H	$CDCl_3$ 31[c]	7·12	2·24				8·38	2·52

[a] X = CH.
[b] 100 MHz.
[c] 60 MHz.
[d] In $CDCl_3$ at 27 °C (100 MHz) δ(H-2): 6·71, δ(H-7): 8·21, δ(H-1): 8·68 ppm.

TABLE 3. BARRIERS TO INTERNAL ROTATION IN INDOLES AND CARBAZOLES

	Solvent	Rotamer E population	Signal observed	T_c K	$\Delta\nu$ Hz	ΔG_c^* kJ mol^{-1}
Indoles						
(1a)	$CDCl_3$	0·35	CHO	288	22	E → Z 61·5 ± 0·5 Z → E 63·1 ± 0·5
(3a)	$CDCl_3$	0·40	CHO	318	19	E → Z 68·1 ± 0·5 Z → E 70·0 ± 0·5
(4a)	$CDCl_3$	0·10	CHO	283	22	E → Z 60·0 ± 0·5 Z → E 66·1 ± 0·5
Carbazoles						
(6a)	THF	0·50	H_1, H_8	298	37·8	62·0 ± 0·3
(6b)	THF	0·50	H_1, H_8	223	44	45·5 ± 0·3
(7a)	THF	0·50	H_1, H_8	300	27·5	62·8 ± 0·4
(7b)	THF	0·50	H_1, H_8	213	36·4	44·0 ± 0·3
Pyrroles						
(8a)[12]	$CDCl_3$	0·50	H_2, H_5	278	21·0	48·6
(8b)[3]	$CDCl_3$	0·50	H_2, H_5	257	22·8	54·0

TABLE 4. CHEMICAL SHIFTS AND COUPLING CONSTANTS FOR SOME CARBAZOLES AT 60 MHz



No.	R	Y	T °C	Solvent	H-1	H-2	H-4	H-8	R
(6a)	H	H	+30	THF	8·04[a]	7·30[b]	7·95	8·04	9·64
			−20	THF	8·54	~7·38[b]	~7·96	7·89	9·72
(6b)	CH_3	H	+30	CCl_4	7·94	7·20[b]	7·70	7·94	2·62
			+30	THF	8·23	7·35[b]	8·15	8·23	Masked by solvent
			−90	THF	8·60[a]	7·98[b]	7·95[a]	7·87	Masked by solvent
(7a)	H	Br	+40	THF	8·10 $J(H_1H_2) = 8·8$	7·55 $J(H_2H_4) = 2·0$	8·18	8·10	9·64
			−20	THF	8·39 $J(H_1H_2) = 8·8$	7·60	8·28	7·95	9·70
			27[c]	$CDCl_3$	8·04 $J(H_1H_2) = 8·7$	7·56 $J(H_2H_4) = 2·2$	8·00 $J(H_1H_4) = 0·5$	8·04	2·81
(7b)	CH_3	Br	−90	THF	8·65 $J(H_1H_2) = 8·9$	7·71[b]	8·49[a]	8·05[a]	Masked by solvent
			+30	THF	8·12 $J(H_1H_2) = 8·9$	7·54 $J(H_2H_4) = 2·2$	8·20	8·12	Masked by solvent

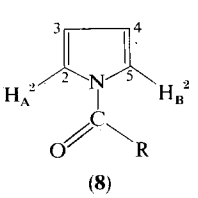
[a] Broad. [b] This value represents the centre of the signals given by protons 2 and 3. [c] At 100 MHz.

barriers are given in Tables 4 and 3, respectively. The most important observation is the great lowering of the barriers in the *N*-acetylcarbazoles compared with the *N*-formyl derivatives. This difference can be explained by the steric hindrance which exists between the methyl group and the protons at positions 1 and 8 in the ring, making the planar state of the molecule less favourable.

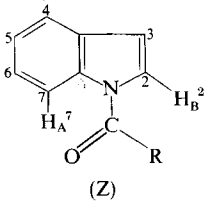
By their symmetry the carbazole derivatives do not exhibit E/Z isomerism, the two configurations being of the same energy.

E/Z configuration (indoles)

The problem of the assignment of H-2 and H-7: carbonyl anisotropy. In all our work on azole NMR spectroscopy (see Introduction) we have made the hypothesis that the heterocyclic hydrogen atom closest to the oxygen of the acyl group (R = H or CH_3) resonates at higher frequencies than that closest to R: $\delta A > \delta B$.



(8)



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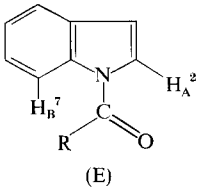

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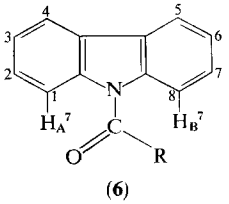


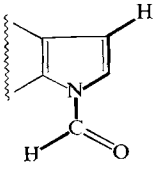
(6)

For *N*-acetylpyrrole (**8b**)† this corresponded with the assignment of Dahlquist and Forsén,[15] and was opposite to that of Matsuo and Shosenji.[12] In fact, the assignment of the latter is closer to the generally accepted model of the anisotropy of the carbonyl group.[16,17] With the parameters we have determined,[18] we have calculated $\delta_A - \delta_B$ for the products **8** and **6**, supposed to be planar and with regular geometry. (Pentagonal side: 1·37 Å; distance N — C(O): 1·42 Å; distance C=O: 1·21 Å). The results are shown in Table 5. The values obtained are equally applicable to protons H-2 and H-7 of indole.

In the case of formyl, the model predicts, as expected, an assignment opposite to that which we adopted but close in absolute value;§ in the case of acetyl the effect depends on the value adopted for $\Delta\chi^{CC}$, which is positive but rather indefinite. Nevertheless, the experimental results show that $\delta_A - \delta_B$ varies little in going from formyl to acetyl.

Having obtained these results, we attempted to establish the E/Z configuration of acylpyrroles and indoles without referring to the anisotropy of the carbonyl group.

In the first instance we used the stereospecificity of the ^5J coupling (see among others Refs. 19 and 20). A coupling of 1·2 Hz is observed between the formyl proton and the proton H-3 of indoles only for the E configuration (zig-zag path).



(E)

This coupling was observed for the formyl proton in the less abundant rotamer of *N*-formylindole (**1a**) (at low temperature) and for *N*-formyl-7-azaindole (**5a**) (at

† It must be noted that the assignment of H_A^2 in the pyrrole (**8b**) conditions that of H_B^7 in carbazole via the indole E.

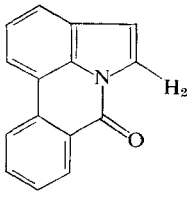
§ We have verified the fact that the observed chemical shifts of H-2 (H_A) and H-5 (H_B) in *N*-acetylpyrrole (**8b**) are independent of the concentration since intramolecular interaction might have been expected.

TABLE 5. CALCULATIONS OF THE EFFECT PRODUCED BY THE ACYL GROUP. ($K = -7{\cdot}4$; $\Delta\chi_1^{CO} = -31{\cdot}1$; $\Delta\chi_2^{CO} = -19{\cdot}6$; $\Delta\chi^{CH} = 0$) (ALL SHIELDING PARAMETERS ARE QUOTED IN UNITS: $\times 10^{-30}$ cm^3/MOLECULE)[18]

	Formyl, R = H	Acetyl, R = CH_3	$\Delta\chi^{CC} = 12{\cdot}5$
Pyrrole (**8**) $\delta_A^2 - \delta_B^2$	−0·66 ppm	$-(0{\cdot}66 - 0{\cdot}031\ \Delta X^{CC})$	−0·27 ppm
Carbazole (**6**) $\delta_A^7 - \delta_B^7$	−0·33 ppm	$-(0{\cdot}33 - 0{\cdot}018\ \Delta X^{CC})$	−0·10 ppm

room temperature, as only one rotamer exists, this having the E configuration); on irradiation of H-3 the coupling disappears. Furthermore, this coupling does not exist in the case of *N*-formylskatole (**3a**). Thus, the favoured rotamer of **1a** has a Z configuration with H-7 shifted towards higher frequencies than in the E configuration.

We have also used lanthanide shift reagents (LSR) to clarify the problem. With amides, LSR complex on to the oxygen atom[21–24] and thus a more pronounced effect is expected on the proton closest to the carbonyl group. We carried out the experiments using Eu(fod)$_3$† on *N*-acetylpyrrole (**8b**) at a temperature low enough to observe separate signals for the protons in positions 2(H_A) and 5(H_B): it is the proton at higher frequencies which is more sensitive to LSR, i.e. H-2(H_A).



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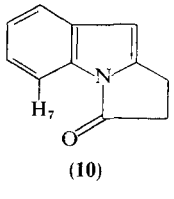
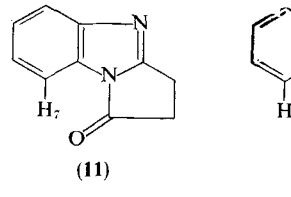


(10)

chemical shift of proton H-2 [~7·80 (solvent $CDCl_3$)][25] is in good agreement with the values in Table 1.

The only rigid derivative we have found to compare with the chemical shift of H-7(H_A) is compound **10**:[26] H-7 appears at lower frequencies than in our indoles (Table 2) by about 0·30 ppm. Such an effect has already been observed[5] when comparing *N*-acetylbenzimidazole with **11**. The presence of two fused 5-membered rings considerably deforms the geometry of the azole. Compound **12** constitutes a better model: in effect proton H-7 appeared shifted by about 0·3 ppm towards higher frequencies compared with H-7 in **11**, (8·21 compared with ~7·95).

By comparison with the *N*-methyl derivatives (Table 6) we can conclude that replacement of a methyl by an acetyl group deshields the protons in the *peri* positions as it deshielded those in the α positions.[1,6]§ This means that those protons close to oxygen are deshielded. We give below the mean displacement towards higher frequencies produced when N—Me is replaced by N—$COCH_3$ (the indole series represents a combination of these).



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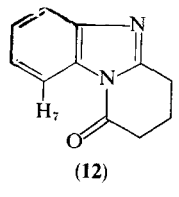
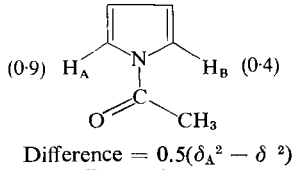
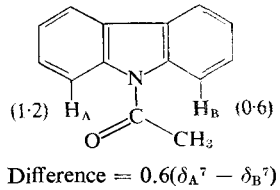


(12)

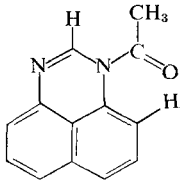


Difference = $0.5(\delta_A^2 - \delta^2)$
Mean effect = 0.65



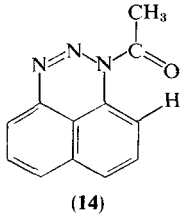
Difference = $0.6(\delta_A^7 - \delta_B^7)$
Mean effect = 0.9

If the chemical shifts of the proton in a *peri* position of **13**, **14** (for which only one rotamer has been observed) and **15** are compared (solvent $CDCl_3$), it can be seen that they are very similar. This shows that the first two have an identical configuration, with the oxygen of the carbonyl group nearest the aromatic ring. The shift occurring when an acetyl group is introduced instead of a methyl group† is indicated in parentheses; the influence of the C=O group is greater than in the indole or carbazole series (about 1·2 ppm).



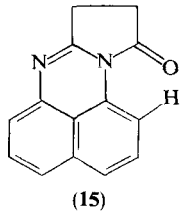
8·26 (2·19)

(13)



8·20 (2·22)

(14)



8·27 § (2·20)

(15)

Therefore, according to these results, it would appear that the classical model of Karabatsos-ApSimon describing the magnetic properties of the carbonyl group does not apply to azoles. One might have thought this to be due to the interaction with the lone pair on nitrogen

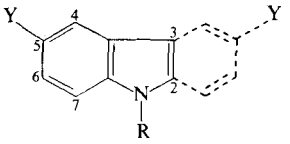
† All the experiments were carried out at different concentrations in Eu(fod)$_3$, the observed shifts being linear with concentration.

§ J. Elguero, L. Pappalardo and M. C. Pardo, unpublished results.

† J. Elguero, C. Marzin and M. Peek, unpublished results.

§ This compound has been compared with 1,2-dimethylperimidine.†

TABLE 6. NMR SPECTRA OF N—H AND *N*-METHYL INDOLES AND CARBAZOLES[a] AT 100 MHZ IN $CDCl_3$



(c) R = H; (d) R = CH_3

No.	R	Y	H-2	H-3	H-4	H-6	H-7
(16c)	H	H	6·99		7·63		7·20[b]
(16d)	CH_3	H	6·94	6·45 J_{23} = 3·2	7·61		7·20 J_{37} = 0·8
(17c)	H	OCH_3	7·01 J_{12} = 2·4	6·44 J_{13} = 2·1 J_{23} = 3·0	7·09 J_{14} = 0·8 $J_{15} \neq 0$ J_{16} = 2·5	6·84 J_{26} = 0·4 J_{67} = 8·4	7·13 J_{37} = 0·9 J_{17} = 0·5
(17d)	CH_3	OCH_3	6·93	6·36 J_{23} = 3·0	7·07 $J_{15} \neq 0$ J_{16} = 2·5	6·86 J_{26} = 0·4 J_{67} = 8·8	7·15 J_{37} = 0·8
(18d)	CH_3[a]	Br[a]	—	—	8·02 J_{46} = 1·9	7·51 J_{67} = 8·7	7·15 J_{47} = 0·5

[a] The numbering in the case of carbazole is different, but here protons in the same positions are compared.
[b] This chemical shift has been determined from a double resonance experiment by irradiating H-3.

but, apart from the fact that this interaction is feeble in azoles, the model can be applied to amides where, agreeing with experiment,[27] it predicts that the methyl close to the carbonyl resonates at the lowest frequencies.[17] Another possibility might be that it does not apply to 5-membered heterocyclic rings, but this is not so since it has been applied with success[28] to *C*-acylfurans[29] where, as for *C*-acylpyrroles[30,31] and *C*-acylthiophenes,[32] it is the proton opposite the carbonyl group which is displaced to low frequencies. The hydrogens occupying *peri* positions (like H-7 in indole) are always described as undergoing a high field shift due to the effect of the carbonyl: see *N*-acylindolines[33–35] and *N*-acylbenzimidazolines[36,37].

The authors of this work have no explanation to offer for the exceptions to the model, nor any empirical rules to propose to predict the exceptions. Care must be taken not to attribute NMR signals or chemical structure solely from the anisotropy of the carbonyl group.

Structural factors influencing the E/Z equilibrium

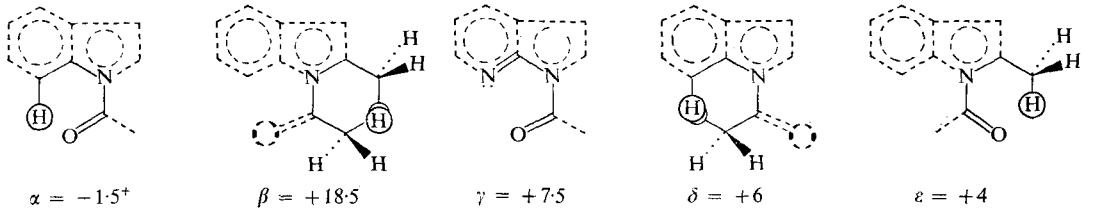
It is first necessary to comment briefly on a publication by Chatterjee and Biswas[38] concerning NMR studies of *N*-formylindoles (**3a** and **4a**) as this contains several errors. (1) These authors have attributed without proof the formyl proton which resonates at highest frequencies (δ9·08 *in* CCl_4) to the rotamer of configuration **3aZ**. This led them to an inversion of the E/Z proportions. (2) They describe proton H-7 belonging to **3aZ** as an enlarged doublet situated at δ8·88 (CCl_4). In the same solvent we observed (Table 2) a broad hump at δ8·36. (3) They describe the existence of only one isomer **4aZ** for *N*-formyl-2,3-dimethylindole. If only one peak for the formyl proton is observed in fact it is because the coalescence temperature is below the ambient temperature at which they ran the spectrum. If the temperature is lowered both isomers can be observed (see Table 3).

Our results on E/Z isomerism are compiled in Table 7, noting the substituents in positions 2 and 7.

TABLE 7. PERCENTAGE OF THE ROTAMER OF Z CONFIGURATION

No.	(a) CHO	(b) $COCH_3$	Position 2	Position 7
(1)	65%	⩾90%	H	CH
(2)	—	⩾90%	H	CH
(3)	60%	⩾90%	H	CH
(4)	90%	⩽10%	CH_3	CH
(5)	⩽10%	⩽10%	H	N

Rather than discussing these percentages qualitatively one by one, we prefer to represent the different attractive (negative energy) or repulsive (positive energy) interactions which must be invoked to explain the results obtained. The figures (in kJ mol^{-1}) are only approximate (having been calculated allowing a 95:5 equilibrium in every case where only one isomer is observed), but they give some idea of the order of energies concerned.



α = −1·5† β = +18·5 γ = +7·5 δ = +6 ε = +4

The buttressing effect of the methyl at position 3 is is certainly responsible for the raised value of β in **4b**.

EXPERIMENTAL

NMR spectra were recorded either on a Varian A 60 or Varian HA 100 spectrometer equipped with a variable temperature controller. The temperature could be measured accurately to ±0·5 °C.

† Other authors[36] consider this to be repulsive interaction.

The chemical shifts are given in ppm relative to TMS as internal reference; coupling constants are given in Hz. The barriers to internal rotation at the coalescence temperature were calculated using the approximate Eyring equation[39] if rotamers E and Z are equally populated, or, if not, using the equation established by Shanan-Atidi and Bar-Eli.[40] The ΔG_c^* values are given in kJ mol^{-1}.

The following compounds were prepared by the literature methods: *N*-formylindole (**1a**),[41] *N*-formylskatole (**3a**),[38]

N-formyl-2,3-dimethylindole (**4a**),[38] *N*-acetylindole (**1b**),[42] *N*-acetyl-5-methoxyindole (**2b**),[43] *N*-acetylskatole (**3b**),[44,45] *N*-acetyl-2,3-dimethylindole (**4b**),[46] *N*-acetyl-7-azaindole (**5b**),[47] *N*-acetylcarbazole (**6b**),[14] *N*-acetyl-3,6-dibromocarbazole (**7b**),[48] *N*-acetylpyrrole **8b**[49] and *N*-methyl-5-methoxyindole (**17d**).[50]

N-*Formyl-7-azaindole* (**5a**). Prepared in the same manner as *N*-formylindole[41] using 3·1 g of 7-azaindole. Chromatography on silica gel using 20% ether + light petroleum as eluent gave *N*-acetyl-7-azaindole (**5b**) (120 mg, 3%), m.p. 65 to 67 °C, Lit.[47], 65 to 66 °C. Further elution with 20% ether + light petroleum gave *N*-formyl-7-azaindole (530 mg, 14%).

N-*Formylcarbazole* (**6a**). Although we used the same method as for *N*-formylindole,[41] we will describe the experiment in some detail as this is the first *N*-formyl derivative of carbazole to have been obtained. 1·2 g Magnesium and a trace of iodine were stirred in absolute benzene (10 ml) and ether (1 ml). Ethyl iodide (8·5 g) was added dropwise and the mixture was heated at 70 °C for 2 to 3 h, cooled to 0 °C and carbazole (4·2 g) suspended in benzene (20 ml) was added. This was stirred for 0·5 h and then ethyl formate (10 ml) was added dropwise. The product was acidified with acetic acid, diluted with water, extracted with ether and the extracts were dried (Na_2SO_4). Chromatography on silica gel using 15% ether + light petroleum as eluent gave *N*-formylcarbazole (0·4 g, 18%), m.p. 94 to 96 °C (*m/e* 195·067; $C_{13}H_9NO$ requires 195·068).

N-*Formyl-3,6-dibromocarbazole* (**7a**). Prepared as above using 2·05 g 3,6-dibromocarbazole (**18c**)[51] as starting material. Chromatography on a silica gel column using 10% ether + light petroleum as eluent **7a** gave (150 mg, 6%) as white needles, m.p. 203 to 205 °C, which decolourised on standing. (*m/e* 352·884; $C_{13}H_7NOBr_2$ requires 352·859).

N-*Methyl-3,6-dibromocarbazole* (**18d**). Attempts to prepare this by the literature method[52] gave only trace amounts. Addition of dimethylsulphate (6 ml) over 0·5 h to a hot (60 to 65 °C) rapidly stirred solution of 3,6-dibromocarbazole (**18c**)[51] (2·5 g) in ethanol (50 ml) with potassium hydroxide (3 ml) gave an immediate precipitate of potassium sulphate. The mixture was refluxed for 0·5 h, poured into water, filtered and the solid obtained was washed with water. Column chromatography of the crude product on silica gel using 10% ether + light petroleum as eluent gave **18d** (1·7 g, 65%) as a white crystalline solid, m.p. 162 to 163 °C from ethanol (Lit.[52] 158 to 160 °C).

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REFERENCES

1. L. Pappalardo, J. Elguero and C. Marzin, *Compt. Rend.* **277C**, 1163 (1973).
2. J. Elguero, C. Marzin and L. Pappalardo, *Bull. Soc. Chim. France* 1137 (1974).
3. J. Elguero, A. Fruchier, L. Knutsson, R. Lazaro and J. Sandström, *Can. J. Chem.* **52**, 2744 (1974).
4. J. Elguero and R. Jacquier, *Compt. Rend.* **260C**, 606 (1965).
5. J.-L. Aubagnac, J. Elguero and R. Robert, *Bull. Soc. Chim. France* 2868 (1972).
6. J. Elguero, A. Fruchier and L. Pappalardo, *Anales Quim.* in press.
7. J. Elguero, A. Fruchier and R. Jacquier, *Bull. Soc. Chim. France* 2075 (1966).
8. J. Elguero, A. Fruchier and R. Jacquier, *Bull. Soc. Chim. France* 3041 (1966).
9. J. Elguero, A. Fruchier and R. Jacquier, *Bull. Soc. Chim. France* 2064 (1969).
10. H. Sauvaitre, J. Teysseyre and J. Elguero, *Bull. Soc. Chim. France* in press.
11. L. Arlinger, K.-I. Dahlquist and S. Forsén, *Acta Chem. Scand.* **24**, 662 (1970).
12. T. Matsuo and H. Shosenji, *Chem. Commun.* 501 (1969).
13. H. A. Staab and D. Lauer, *Chem. Ber.* **101**, 864 (1968).
14. J. Polaczek, *Zesz. Nauk. Inst. Ciezkiej Synt. Org. Blachowni Slask.* **3**, 65 (1971). *Chem. Abstr.* **77**, 139020 (1972).
15. K.-I. Dahlquist and S. Forsén, *J. Phys. Chem.* **73**, 4124 (1969).
16. G J. Karabatsos, G. C. Sonnischen, N. Hsi and D. J. Fenoglio, *J. Amer. Chem. Soc.* **89**, 5067 (1967).
17. J. W. ApSimon, P. V. Demarco, D. W. Mathieson, W. G. Craig, A. Karim, L. Saunders and W. B. Whalley, *Tetrahedron* **26**, 119 (1970).
18. J. W. ApSimon, J. Elguero, A. Fruchier, D. Mathieu and R. Phan-Tan-Luu, *Can. J. Chem.* **52**, 2296 (1974).
19. B. R. Larsen, F. Nicolaisen and J. T. Nielsen, *Acta Chem. Scand.* **26**, 1736 (1972).
20. M. Farnier and T. Drakenberg, *Tetrahedron Letters* 429 (1973).
21. C. Beauté, Z. W. Wolkowski and N. Thoai, *Chem. Commun.* 700 (1971).
22. A. Lewin, *Tetrahedron Letters* 3583 (1971).
23. T. H. Sidall, *Chem. Commun.* 452 (1971).
24. R. A. Fletton, G. F. H. Green and J. E. Page, *Chem. Commun.* 1134 (1972).
25. W. Carruthers and N. Evans, *J. Chem. Soc. Perkin I* 1523 (1974).
26. G. R. Cliff, G. Jones and J. McK. Woolard, *J. Chem. Soc. Perkin I* 2072 (1974).
27. F. A. L. Anet and A. J. R. Brown, *J. Amer. Chem. Soc.* **87**. 5250 (1965).
28. M. L. Martin, J.-C. Roze and G. J. Martin, *Tetrahedron Letters* 3407 (1970).
29. B. Roques, S. Combrisson, C. Riche and C. Pascard-Billy, *Tetrahedron* **26**, 3555 (1970).
30. L. Arlinger, K.-I. Dahlquist and S. Forsén, *Acta Chem. Scand* **24**, 672 (1970).
31. M. C. Fournié-Zaluski, C. Jaureguiberry and B. Roques, *Tetrahedron Letters* 4177 (1973).
32. S. Nagata, T. Yamabe and K. Fukui, *Tetrahedron* **30**, 1315 (1974).
33. K. Nagarajan, N. D. Nair and P. M. Pillai, *Tetrahedron* **23**, 1683, 4493 (1967).
34. S. McLean, U. O. Trotz, C. J. MacDonald, W. F. Reynolds and D. J. Wood, *Can. J. Chem.* **49**, 1638 (1971).
35. A. M. Monro and M. J. Sewell, *J. Chem. Soc.* (*B*) 1227 (1971).
36. G. V. Garner, O. Meth-Cohn and H. Suschitzky, *J. Chem. Soc.* (*C*) 1234 (1971).
37. W. Walter and U. Sewekow, *Liebigs Ann. Chem.* 274 (1974).
38. A. Chatterjee and K. M. Biswas, *J. Org. Chem.* **38**, 4002 (1973).
39. A. Frost and R. Pearson, *Kinetic Mechanismus homogener chemischer Reaktionen*, Verlag Chemie, 1967.
40. H. Shanan-Atidi and K. H. Bar-Eli, *J. Phys. Chem.* **74**, 961 (1970).
41. N. Potokhin, *Russ. J. Phys. Chem.* **59**, 761 (1927).
42. H. Pleininger and G. Werst, *Chem. Ber.* **89**, 2783 (1956).
43. K. G. Blaikie and W. H. Perkin, *J. Chem. Soc.* **125**, 296 (1924).
44. B. Oddo, *Gazz. Chim. Ital.* **4311**, 190 (1913).
45. A. Borsodi and T. Tóth, *Magy. Kém. Folyoirat* **75**, 251 (1969).
46. C. M. Atkinson, J. C. E. Simpson and A. Taylor, *J. Chem. Soc.* 165 (1954).
47. B. A. J. Clark and J. Parrick, *Tetrahedron* **30**, 475 (1974).
48. F. Muzik and Z. J. Allan, *Collection Czech. Chem. Commun.* **22**, 641 (1957).
49. P. Linda and G. Marino, *Ric. Sci.* **37**, 424 (1967).
50. R. G. Taborsky, R. Delvigs, I. H. Page and N. Crawford, *J. Med. Chem.* **8**, 460 (1965).
51. V. P. Lopatinskii and I. P. Zherebetsov, *Metody Polucheniya. Khim. Reakt. Preparatov* **11**, 46 (1964); *Chem. Abstr.* **65**, 2003 (1966).
52. H. Lindeman and F. Mülhaus, *Chem. Ber.* **58B**, 2371 (1925).