JOURNAL OF PHYSICAL ORGANIC CHEMISTRY, VOL. 9, 137–144 (1996)

AROMATIC PROPELLENES. PART 2. STUDY OF CONFORMATIONAL ISOMERISM OF HEXA(PYRAZOL-1-YL)BENZENE: X-RAY CRYSTALLOGRAPHY AND SEMIEMPIRICAL CALCULATIONS

CONCEPCIÓN FOCES-FOCES* AND ANTONIO L. LLAMAS-SAIZ
Departamento de Cristalografía, Instituto de Química-Física 'Rocasolano,' CSIC, Serrano 119, E-28006 Madrid, Spain

CONSUELO ESCOLÁSTICO AND ROSA MARÍA CLARAMUNT*
Departamento de Química Orgánica y Biología, Facultad de Ciencias, UNED, Senda del Rey s/n, E-28040 Madrid, Spain

AND

JOSÉ ELGUERO
Instituto de Química-Médica, CSIC, Juan de la Cierva 3, E-28006 Madrid, Spain

The molecular and crystal structures of two crystalline forms of hexa(pyrazol-1-yl)benzene were determined by x-ray analysis. They correspond to two conformational polymorphs: form I is obtained in acetic acid and form II in ethanol or dichloromethane. The crystal packing of both conformers is different; however, that of form I is analogous to that of hexa(3,5-dimethylpyrazol-1-yl)benzene, having similar cell dimensions and space groups *R*-3. No significant interactions except the van der Waals interactions were observed. Semiempirical calculations at the AM1 and SAM1 levels, exploring all possible conformations of the pyrazole rings, reveal that the most stable conformation presents the pyrazole rings with the N(2) alternating between both sides of the phenyl plane as it occurs in the solid state, crystalline form I (conformation 8h). The computed minimum energy for conformer 7a, which is related to crystal form II, presents a different sequence of pyrazole arrangements [N(2) *up* or *down*] and is only 1·6–2·0 kcal mol^{-1} less stable than the previous one in both parametrizations. The SAM1 method yields pyrazole moieties more perpendicular to the benzene ring than the AM1 one.

INTRODUCTION

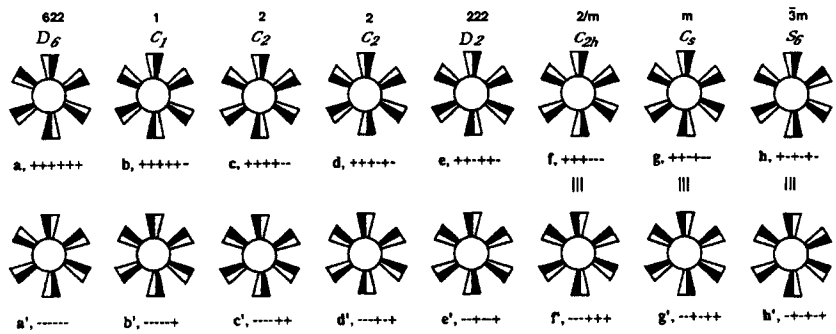
We are exploring the structure and conformational space of a series of compounds we have called 'Aromatic Propellenes.'[1] These compounds, related to hexaphenylbenzene[2] and to the hexa(4-dimethylamino-1-pyridinium)benzene hexacation,[3] present eight conformations (Scheme 1) depending on the orientation of the blade with regard to shaft. If the six dihedral angles τ_i were equal to 90°, then all conformations collapse to one, but allow one assume they were all identical in absolute value but different from 90°. In this case, there are eight conformations **a**–**h** and the corresponding mirror images (enantiomers) **a**′–**h**′. In the three cases where there are an equal number of + and − signs, the mirror images have the same global situation (three + and three −) being identical, i.e. **f** = **f**′, **g** = **g**′ and **h** = **h**′. All eight conformations are separated by a barrier through the orthogonal position, a barrier that must be weak and easy to overcome. In hexa(pyrazol-1-yl)benzenes (all pyrazoles identical), a second source of isomerism appears since the C_2 symmetry of phenyl and 4-dimethylamino-1-pyridinium is lost.

The problem is related to the case of hexaarylbenzenes discovered by Gust and Patton[4,5] and studied exhaustively by Willem and co-workers.[6–8] There are eight possible isomers **1**–**8** (Scheme 2),[1] depending on whether the N(2) atom is *up* (black circle *u*) or *down* (white circle *d*). In this case, isomerization implies going through the planar conformation which is much more energy requiring. For this reason, in Scheme 3 the conformations are connected through lines which correspond to rotation of one pyrazole at a time (the so-called M_1[5,8] or M[1,7] mode of internal rotation). In summary, hexapyrazolylbenzenes will present in the simplest case (all pyrazoles identical) a total of 192 conformations, 18 of these being achiral (see Supplementary Material). For instance, hexa(3,5-

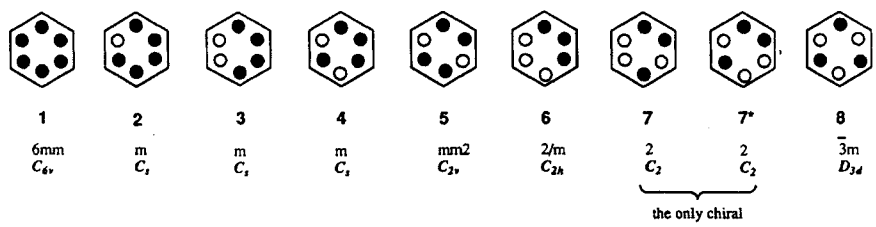
* Author for correspondence.

CCC 0894–3230/96/030137–08

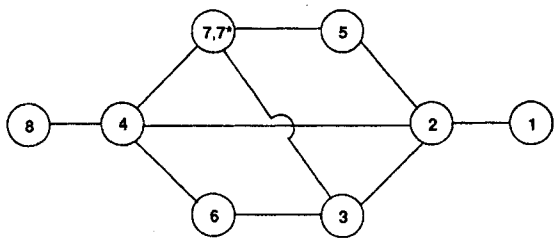
Received 11 August 1995
Revised 15 November 1995



Scheme 1



Scheme 2



Scheme 3

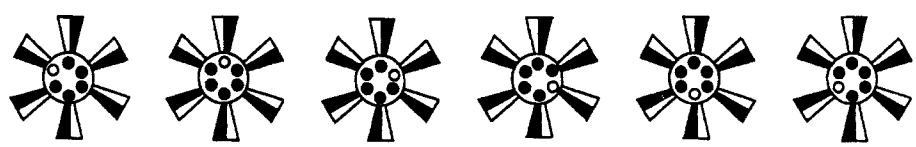
dimethylpyrazol-1-yl)benzene crystallizes in the conformation **8h**.[1] We shall use this system of notation in this paper and in the following, the figure will describe the rotational isomerism of pyrazoles (high barrier) and the letter the conformation, left or right, with regard to the perpendicular conformation (low barrier), adding a subindex when necessary. It must be realized that, for instance, six different conformations correspond to the case **2b** (Scheme 4).

The 'configurational' problem, **1**–**8**, has been recognized by all authors[4–8] but, since they were interested in NMR in solution and in stereoisomerizations through planar conformations, they neglected the 'conformational' problem, **a**–**h**, assuming, for all practical purposes, a perpendicular conformation ($\tau_i = \pm 90°$).

RESULTS AND DISCUSSION

X-ray analysis

Bond distances, angles and torsion angles are listed in Table 1. The molecule, in form **I**, is located on a threefold rotary inversion axis, and therefore there is only one pyrazole in the asymmetric unit and the N(2) atoms are placed *up* (*u*) and *down* (*d*) with respect to the benzene ring (Figure 1) and they are almost perpendicular to it [85·1(3)°] as in hexa(4-dimethylamino-1-pyridinium)benzene hexacation (80·0°).[3] The pyrazole rings, in form **II**, are placed *uddduud* and they are less perpendicular to the benzene ring than in form **I** (Figure



Scheme 4

Table 1. Selected geometrical parameters for crystal forms **I** and **II** and the corresponding calculated conformers **7** and **8** (Å, °)

		Conformers **7** and **8**	
Form **I**	Exp.	AM1	SAM1
N(*i*1)—N(*i*2)	1·353(2)	1·353	1·318
N(*i*1)—C(*i*5)	1·338(2)	1·409	1·428
N(*i*2)—C(*i*3)	1·323(2)	1·352	1·352
C(*i*3)—C(*i*4)	1·377(2)	1·451	1·479
C(*i*4)—C(*i*5)	1·352(2)	1·396	1·419
N(*i*1)—C(*i*)	1·417(2)	1·422	1·427
C(*i*)—C(*i* + 1)	1·391(2)	1·421	1·431
C(*i*5)—N(*i*1)—C(1)	128·7(1)	125·2	125·8
N(*i*2)—N(*i*1)—C(1)	119·4(1)	122·8	122·5
N(*i*2)—N(*i*1)—C(*i*5)	111·9(2)	112·0	111·7
N(*i*1)—N(*i*2)—C(*i*3)	103·9(2)	106·3	109·3
N(*i*2)—C(*i*3)—C(*i*4)	112·1(2)	110·7	108·8
C(*i*3)—C(*i*4)—C(*i*5)	105·1(2)	104·9	104·5
N(*i*1)—C(*i*5)—C(*i*4)	107·0(2)	106·2	105·7
N(*i*1)—C(*i*)—C(*i* + 1)	120·0(1)	120·0	120·0
N(*i*2)—N(*i*1)—C(*i*)—C(*i* + 1)	−85·1(3)		
Hydrogen interaction:	X—H	H···Y	X···Y	X—H···Y
C(15)—H(15)···N(12) (*x*, *y*, *z* − 1)	0·95(3)	2·47(3)	3·346(2)	152(3)

Form **II**	*i* = 1	*i* = 2	*i* = 3	*i* = 4	*i* = 5	*i* = 6
N(*i*1)—N(*i*2)	1·351(7)	1·365(7)	1·357(8)	1·363(9)	1·359(7)	1·366(7)
N(*i*1)—C(*i*5)	1·358(8)	1·357(9)	1·336(8)	1·356(8)	1·361(9)	1·361(8)
N(*i*2)—C(*i*3)	1·330(10)	1·324(11)	1·346(8)	1·321(10)	1·330(10)	1·338(8)
C(*i*3)—C(*i*4)	1·373(11)	1·407(11)	1·369(11)	1·377(12)	1·407(11)	1·379(10)
C(*i*4)—C(*i*5)	1·368(10)	1·352(11)	1·360(9)	1·356(11)	1·356(12)	1·365(9)
N(*i*1)—C(*i*)	1·428(7)	1·415(9)	1·421(7)	1·421(8)	1·412(10)	1·413(7)
C(*i*)—C(*i* + 1)	1·394(7)	1·386(9)	1·390(10)	1·391(8)	1·387(9)	1·395(8)
C(*i*5)—N(*i*1)—C(*i*)	126·6(5)	127·8(5)	128·9(5)	127·6(6)	126·3(5)	129·7(5)
N(*i*2)—N(*i*1)—C(*i*)	120·2(4)	120·5(6)	119·5(4)	120·0(5)	120·8(5)	118·4(4)
N(*i*2)—N(*i*1)—C(*i*5)	113·0(5)	111·6(6)	112·4(5)	112·2(5)	112·8(6)	111·8(5)
N(*i*1)—N(*i*2)—C(*i*3)	102·9(5)	104·2(6)	103·2(5)	103·4(6)	103·5(5)	103·6(5)
N(*i*2)—C(*i*3)—C(*i*4)	113·2(6)	111·9(7)	111·9(6)	112·5(7)	111·9(7)	112·4(6)
C(*i*3)—C(*i*4)—C(*i*5)	105·3(6)	104·9(7)	105·6(6)	105·9(7)	105·5(7)	105·7(6)
N(*i*1)—C(*i*5)—C(*i*4)	105·7(6)	107·4(6)	107·0(6)	105·9(6)	106·2(6)	119·9(5)
N(*i*1)—C(*i*)—C(*i* + 1)	120·0(4)	120·5(5)	118·9(6)	120·3(5)	120·2(5)	119·4(6)
N(*i*2)—N(*i*1)—C(*i*)—C(*i* + 1)	−80·4(7)	−51·3(8)	104·6(7)	−63·1(8)	122·4(6)	116·7(6)
Hydrogen interactions:		X—H	H···Y	X···Y	X—H···Y	
C(14)—H(14)···N(22)(1/2 + *x*, 3/2 − *y*, *z*)		1·01(19)	2·89(10)	3·440(9)	115(7)	
C(15)—H(15)···N(12)(1/2 + *x*, 3/2 − *y*, *z*)		1·07(7)	2·57(7)	3·468(8)	142(5)	
C(34)—H(34)···N(32)(−1/2 + *x*, 1/2 − *y*, *z*)		0·93(8)	2·83(8)	3·467(9)	126(6)	
C(45)—H(45)···N(32)(*x*, *y*, *z*)		1·06(8)	2·98(8)	3·440(11)	107(5)	
C(53)—H(53)···N(32)(1 − *x*, 1 − *y*, 1/2 + *z*)		1·08(8)	2·79(8)	3·584(11)	131(5)	
C(55)—H(55)···N(52)(−1/2 + *x*, 3/2 − *y*, *z*)		0·89(8)	2·86(8)	3·657(9)	151(6)	
C(63)—H(63)···N(42)(1/2 + *x*, 3/2 − *y*, *z*)		1·05(7)	2·48(7)	3·528(9)	175(5)	
C(65)—H(65)···N(12)(*x*, *y*, *z*)		1·04(11)	2·91(10)	3·383(11)	108(7)	

2), in a similar way to the phenyl rings in hexaphenylbenzene (range 64·3–69·1°).[2] In spite of the large standard deviations of data in form **II**, the bond distances in the independent pyrazole in **I** are found in the lower end of the range presented by these distances in **II**, that would suggest a greater degree of charge delocalization in **I** (Table 1). The differences detected in **II**, although just a few of them, in the limit of significance, are

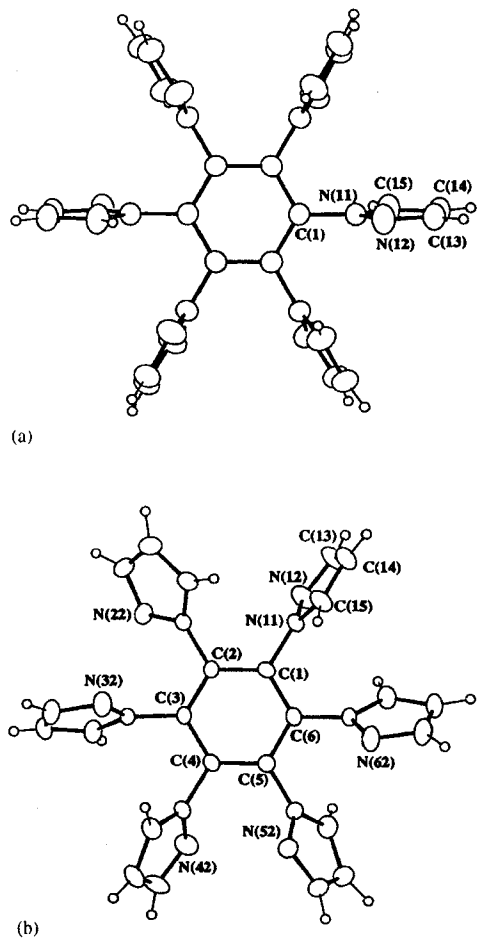


Figure 1. (a) An Ortep[18] view of form **I** as projected on the benzene ring. (b) Same for form **II**. Ellipsoids are drawn at the 30% probability level

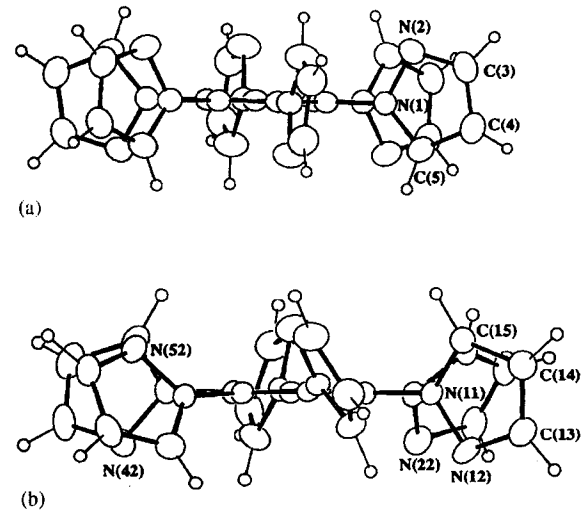


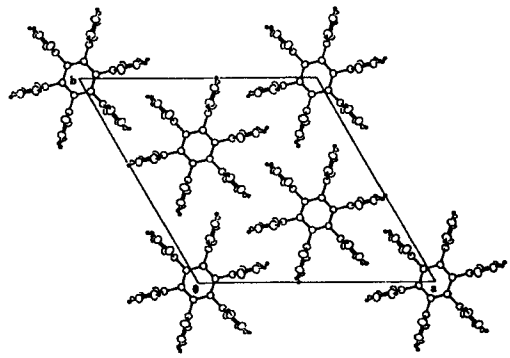
Figure 2. (a) A perpendicular view to that of Figure 1 showing the numbering system and the conformation of the molecules in form **I**. (b) Same for form **II**

probably due to packing forces. The crystal is built up of discrete molecules which do not bear any significant interactions among them. Figure 3 shows both crystal structures for comparison purposes. The low total packing coefficient for **I** ($C_k^{all} = V_{molecules}$/unit cell volume = 0·65) is consistent with the presence of spherical voids in the structure[9] of volume 15·2 Å^3 and centred at the crystallographic origin and at their symmetrically related sites, analogously to the previously studied compound.[1] In form **II**, there are no voids in the structure and the total packing coefficient is 0·69.

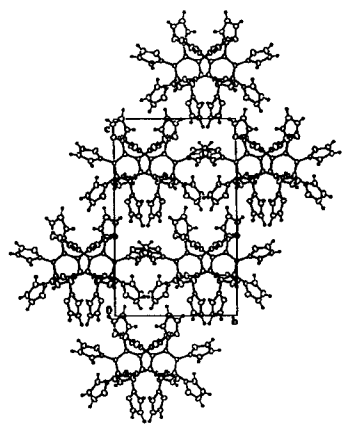
Semiempirical computations

The bond distances and angles of the optimized molecular structure for both forms are given in Table 1 together with the experimental values. Only the averaged geometry is listed since the greater differences, up to 0·5°, correspond to the C(*i*)—N(*i*1)—N(*i*2) or C(*i*)—N(*i*1)—C(*i*5) external angles. No correlation was found depending on whether the N(2) atom is placed *up* or *down* with respect to the benzene ring. In both cases AM1 and SAM1, the agreement is reasonable but there are some small differences that are worth mentioning: all bond distances, except N(*i*1)—N(*i*2) in SAM1, are longer than the experimental values; this elongation is larger in N(1)—C(5) and C(3)—C(4), pointing to a lower degree of charge delocalization in the pyrazole ring; the angles at N(*i*2) and C(*i*3) have their values interchanged in the SAM1 model.

The optimized values of the energy, dipolar moments and torsion angles between the phenyl and pyrazole rings for the eight conformers are listed in Tables 2 and 3. In general, the computed conformations are in good agreement with the experimental ones. Two different conformations close in energy [0·4 kcal mol^{-1} (1 kcal = 4·184 kJ)] corresponding to the *D*3 and *S*6 point groups were obtained for conformer **8** when the AM1 model is considered (**8a** and **8h**, respectively). In the computed conformation **8h** (analogous to that found in the crystal structure, form **I**), the C(*i*5)—H···N(*i*2) interaction between contiguous pyrazole rings is overestimated, and the value of the N(*i*2)—N(*i*1)—C—C torsion angle diminishes (always in absolute value) resulting in the approximation of the C(*i*5) and N(*i*2) atoms from different pyrazole rings. The value of these torsion angles is even smaller in the pseudohelicoidal conformer **8a**, which has the energy minimum of this series. The energy increases with the number of con-



(a)



(b)

Figure 3. (a) Crystal packing of **I** down the *c* axis. (b) Same for compound **II** down the *a* axis

tiguous pyrazoles having the N(*i*2) atom on the same side of the benzene ring. Both theoretical models yield the same sequence of increasing energy for the eight conformers.

All the AM1-calculated molecules for the eight different *up* and *down* combinations of the N(*i*2) atom present a pseudohelicoidal conformation as the energy minimum (denoted by *a*). The N(*i*2)—N(*i*1)—C—C torsion angles are always close to −60 and 120° (Table 2). When the SAM1 parametrization is used the pyrazole moieties are mainly perpendicular to the central ring. Only in the situations **3**, **2** and **1**, where there are four, five and six consecutive pyrazoles in the same orientation, respectively, are the torsion angles significantly different from 90°. The mean values for these angles are −82.8, −79.2 and −74.9° for **3**, **2** and **1**, respectively (Table 3). The perpendicular disposition of these rings in conformers **4**–**8** is the cause of the presence of symmetry planes perpendicular to the central ring increasing the point group symmetry. There is an exception with **3** because in this case the special *up* and *down* sequence of the pyrazole rings makes this case the only one which is chiral with absolute independence of the torsion angles values. The presence of a mirror plane in this conformer is not possible in any case.

In the case of hexa(3,5-dimethylpyrazol-1-yl)benzene [(dmpz)$_6$bz], we have used an empirical relationship to estimate the value of the different interactions in this system.[1] If the N(*i*2) are on the same side and in *ortho* [1,2], *meta* [1,3] or *para* [1,4] positions with regard to the central benzene ring, the following equation was found (for AM1 heats of formation in kcal mol^{-1}):

$$\Delta H(\mathrm{AM1}) = 452{\cdot}2 + 4{\cdot}0\,[1,2] - 0{\cdot}3\,[1,3] + 1{\cdot}6\,[1,4], \quad n = 8, \quad r^2 = 0{\cdot}976 \quad (1)$$

Table 2. AM1 calculations of the main conformers of (pz)$_6$bz: heats of formation, ΔH, and differences in heats of formation, $\delta\Delta H$, in kcal mol^{-1}, dipole moments in D, point groups, torsion angles (°) and helicities

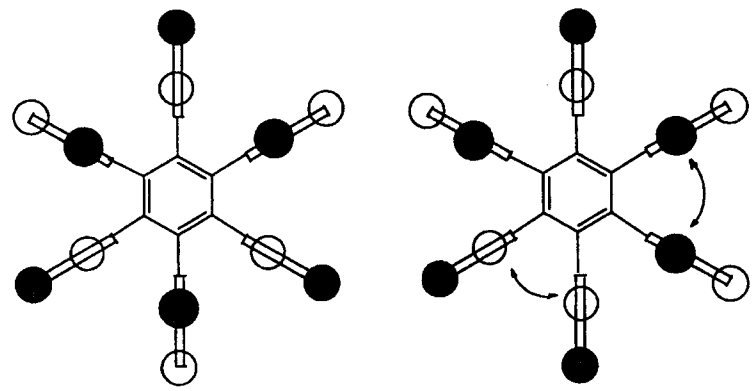
Parameter	**1**	**2**	**3**	**4**[a,b]	**5**	**6**	**7**[b]	**8**[a]	**8**
ΔH	546·9	543·7	543·1	541·0	540·9	543·0	540·8	538·8	539·2
$\delta\Delta H$	8·1	4·9	4·3	2·2	2·1	4·2	2·0	0·0	0·4
Dipole moment	8·34	5·63	3·75	3·06	2·65	2·99	1·59	0·0	0·0
Point group	C_6	C_1	C_1	C_1	C_2	C_2	C_2	D_3	S_6
τ_1	−57·3	−60·0	116·5	−60·7	−60·8	120·4	−61·4	−61·4	−73·4
τ_2	−57·3	−57·8	−61·4	116·8	−57·4	118·2	121·7	119·2	73·4
τ_3	−57·3	−57·4	−58·2	−60·5	116·6	−62·5	117·8	−61·4	−73·4
τ_4	−57·3	−57·6	−58·0	−58·3	−60·8	−58·9	−62·7	119·2	73·4
τ_5	−57·3	−56·8	−56·8	−57·9	−57·4	−57·3	−57·7	−61·4	−73·4
τ_6	−57·3	114·6	120·6	117·5	116·6	121·9	118·8	119·2	73·4
Helicity	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**a**	**h**

[a] $TS_{(8\rightarrow4)}^{\ddagger}$, $\delta\Delta H$ = 12·6 kcal mol^{-1}.
[b] $TS_{(4\rightarrow7)}^{\ddagger}$, $\delta\Delta H$ = 12·0 kcal mol^{-1}.

Table 3. SAM1 calcultations of the main conformers of $(pz)_6bz$: heats of formation, ΔH, and differences in heats of formation, $\delta\Delta H$, in kcal mol^{-1}, dipole moments in D, point groups and torsion angles

Parameter	**1**	**2**	**3**	**4**[a,b]	**5**	**6**	**7**[b]	**8**[a]
ΔH	435·3	431·5	430·4	428·3	428·1	430·2	427·8	425·9
$\delta\Delta H$	9·4	5·6	4·5	2·4	2·2	4·3	1·9	0·0
Dipole moment	11·17	7·54	3·81	3·84	3·84	0·0	0·17	0·0
Point group	C_6	C_1	C_1 (near C_s)	C_1	C_{1v}	C_{2h}	C_2	D_{3d}
Torsions	$\tau_i \pm 90°$ in most cases with some exceptions (see text)							

[a] $TS_{(8\rightarrow4)}^{\ddagger}$, $\delta\Delta H = 11{\cdot}9$ kcal mol^{-1}.
[b] $TS_{(4\rightarrow7)}^{\ddagger}$, $\delta\Delta H = 10{\cdot}6$ kcal mol^{-1}.



ududud *uddduud*

Scheme 5

For $(pz)_6bz$, the results in Tables 2 and 3 led to the equations

$$\Delta H(\text{AM1}) = 537{\cdot}4 + 1{\cdot}3\ [1,2] + 0{\cdot}2\ [1,3] + 0{\cdot}2\ [1,4], \quad n = 8, \quad r^2 = 1{\cdot}000 \quad (2)$$

$$\Delta H(\text{SAM1}) = 423{\cdot}6 + 1{\cdot}4\ [1,2] + 0{\cdot}4\ [1,3] + 0{\cdot}3\ [1,4], \quad n = 8, \quad r^2 = 1{\cdot}000 \quad (3)$$

Clearly, the main term continues to be the [1,2] interaction (1·3–1·4 kcal mol^{-1}), but it is much weaker in the second case, explaining why $(dmpz)_6bz$ exists in the **8** conformation while $(pz)_6bz$ exists both in the **8** and **7** conformations. We assign these differences to the methyl group at position 5 of the pyrazole ring (see Scheme 5) which destabilize the *uu* (or *dd*) [1,2] interaction. Willem and co-workers[6,8] approached the problem of rotamer population (determined experimentally by ^{1}H NMR spectroscopy and HPLC) in a different way. They calculated for the [1,2] interaction of two *o*-anisyl groups, $\Delta G_{cis} - \Delta G_{trans}$, a value of 0·4 kcal mol^{-1}.

Since the conformational polymorphs belong to structures **8** and **7**, we have calculated the barriers corresponding to the path **8** → **4** → **7** (see Tables 2 and 3 and Scheme 3). The lines in Scheme 3 represent all single interconversion paths between conformers when only one pyrazole is turned *up–down* (about 180°).[10] These barriers correspond to a geometry optimization keeping one pyrazole ring coplanar with the benzene ring. Since the second barrier (**4** → **7**, 10·6 kcal mol^{-1}) is slightly lower than the first (**8** → **4**, 11·9 kcal mol^{-1}) and since isomer **7** is more stable than isomer **4**, these calculations account for isolating **8** and **7**. These calculated activation barriers also explain why in solution both polymorphs present the same NMR spectra (^{1}H, ^{13}C) which should correspond to the average of of the spectra **7** and **8**.

A series of experiments were carried out to obtain more information about the conformational polymorphism of $(pz)_6bz$, structures **I**(**8h**) and **II**(**7a**), and about the fact that the last solvent of crystallization is responsible for the crystal structure. Cross-experiments were carried out dissolving in ethanol crystals obtained in acetic acid, and reciprocally; in both cases, the structure (same unit cell and symmetry) corresponds to that of the last solvent used.

.Table 4. Crystal analysis parameters at room temperature

Parameter	I	II
Crystal data		
Formula	$C_{24}H_{18}N_{12}$	$C_{24}H_{18}N_{12}$
Crystal habit	Colourless, hexagonal prism	Colourlesss, hexagonal plate
Crystal size (mm)	0·67 × 0·27 × 0·27	0·20 × 0·20 × 0·13
Symmetry	Rombohedral, *R*-3	Orthorhombic, $Pna2_1$
Unit cell determination	Least-squares fit from 50 reflections ($\theta < 45°$)	Least-squares fit from 80 reflections ($\theta < 45°$)
Unit cell dimensions (Å, °)	$a = 19·1381(8)$ $b = 19·1381(8)$ $c = 5·5469(2)$ 90, 90, 120	$a = 9·6977(3)$ $b = 11·9861(15)$ $c = 19·4946(5)$ 90, 90 90
Packing: V (Å^3), Z	1759·5(1), 3	2266·0(3), 4
D_c (g cm^{-3}), M, $F(000)$	1·343, 474·49, 738	1·391, 474·49, 984
μ (cm^{-1})	6·86	7·10
Experimental data		
Technique	Four circle diffractometer: Philips PW1100, bisecting geometry. Graphite oriented monochromator. $\omega/2\theta$ scans. Detector apertures 1 × 1°. 1 min/reflection.	
Radiation	Cu Kα	Cu Kα
Scan width (°)	1·5	1·5
θ_{max} (°)	65	65
Number of reflections:		
Independent	659	2020
Observed	610 [$3\sigma(I)$ criterion]	1553 [$3\sigma(I)$ criterion]
Standard reflections	2 reflections every 90 minutes	
	No variation	2·5% decay
Solution and refinement		
Solution	Direct methods: Sir92	
Refinement		
Least-squares on F_o	Full matrix	
Parameters		
Number of variables	67	396
Degrees of freedom	543	1157
Ratio of freedom	9·1	3·9
Final shift/error	0·02	0·03
H atoms	From difference synthesis	
Weighting scheme	Empirical so as to give no trends in $\sim\langle\omega\Delta^2F\rangle$ vs $\langle\lvert F_{obs}\rvert\rangle$ and $\langle\sin\theta/\lambda\rangle$	
Max. thermal value (Å^2)	$U22$[C(15)] = 0·099(1)	$U33$[C(13)] = 0·085(5)
Final ΔF peaks (e Å^{-3})	0·14	0·20
Final R and R_w	0·046, 0·052	0·048, 0·051

EXPERIMENTAL

The ^{1}H and ^{13}C NMR spectra in solution were recorded on a Bruker AC200 instrument operating at 200·13 MHz (^{1}H) and 50·32 MHz (^{13}C) using standard conditions.[11] The ^{13}C CP/MAS spectrum was recorded in the same instrument using the conditions described in Ref 12.

Synthesis. Hexa(pyrazol-1-yl)benzene was prepared according to Henrie and Yeager's procedure.[13] They described the product in the following manner: $C_{24}H_{18}N_{12} \cdot H_2O$ (note that both crystal structures, **I** and **II**, appear to be anhydrous) C, H, N, M^+ 474, and m.p. >400 °C. To a solution of 2 g (29·4 mmol) of pyrazole in 20 ml of dry tetrahydrofuran (THF) under an argon atmosphere was added 0·71 g (29·4 mmol) of NaH (60% oil dispersion) in small amounts. The solution was heated at 65 °C for 1 h; after cooling, 0·57 ml

(4·9 mmol) of hexafluorobenzene was added. The mixture was refluxed for 6 h. The white precipitate was filtered off and washed with 20 ml of water and then with 20 ml of THF. Yield, 91%, m.p. >350 °C (decomp.). ^{1} NMR (200 MHz, $CDCl_3$), δ 7·41 (dd, $H_{3'}$), 6·13 (dd, $H_{4'}$, $J_{4'5'} = 2·5$, $J_{3'4'} = 1·8$ Hz), 7·25 (dd, $H_{5'}$, $J_{3'5'} = 0·4$ Hz); (200 MHz, $CDCl_3 + CF_3CO_2H$), δ 7·69 (dd, $H_{3'}$), 6·37 (dd, $J_{4'5'} = 2·6$, $J_{3'4'}$, = 2·0 Hz), 7·36 (dd, $H_{5'}$). ^{13}C NMR (50 MHz, $CDCl_3$), δ 136·6 (C_1), 141·5 ($C_{3'}$, $^1J = 187·2$, $^2J = 6·0$, $^3J = 8·2$ Hz), 107·2 ($C_{4'}$, $^1J = 178·5$, $^2J = 10.0$, $^3J = 8·7$ Hz), 132·3 ($C_{5'}$, $^1J = 191·5$, $^2J = 9·2$, $^3J = 4·5$ Hz); (50 MHz, solid state, CP/MAS), δ 135·7 (C_1), 142·1 ($C_{3'}$), 107·8 and 110·1 ($C_{4'}$), 130·9 and 133·2 ($C_{5'}$). Two different crystalline forms were obtained depending on the solvent used for crystallization: form **I** from acetic acid (m.p. >350 °C) and form **II** from ethanol or CH_2Cl_2 (m.p. >350 °C).

X-ray analysis. The experimental details and the most relevant parameters of the refinement are given in Table 4. The structures were solved by direct methods, Sir92.[14] The non-hydrogen atoms were refined anisotropically and the hydrogen atoms were included as isotropic. One reflection for compound **I** was affected by secondary extinction and was considered as unobserved in the last cycles of refinement. Most of the calculations were performed on a VAX6410 computer using the XRAY80 system.[15] The atomic scattering factors were taken from Ref. 16.

Semiempirical calculations. The molecular structures for the eight possible combinations of *up* and *down* pyrazoles were optimized using the AM1 and SAM1 parametrizations of the hamiltonian as implemented in the AMPAC5.0[17] package. The only restriction imposed was the planarity of the pyrazole and benzene rings. The crystallographic coordinates of form **I** were used as starting point. The remaining conformations were generated twisting the corresponding pyrazole rings around the N(*i*1)—C(*i*) bond. Several starting points were generated for each case in a systematic way in order to avoid local minima. The caLculations were performed using an ALPHA3000-300X DECstation.

SUPPLEMENTARY MATERIAL

Lists of the structure factors, atomic coordinates and thermal components for the non-hydrogen atoms, hydrogen atom parameters, bond distances and angles and the complete list of 192 possible conformers of $(pz)_6bz$ (nomenclature and point groups symmetry) are available from C.F.-F on request.

ACKNOWLEDGEMENTS

Thanks are due to the DGICYT (Spain) for financial support (PB93-0197-C02-01 and PB93-0125) and to Professors Alexander T. Balaban (Bucharest) and Rudolph Willem (Brussels) for useful comments.

REFERENCES

1. C. Foces-Foces, A. L. Llamas-Saiz, R. M. Claramunt, N. Jagerovic, M. L. Jimeno and J. Elguero, *J. Chem, Soc., Perkin Trans. 2* 1359–1363 (1995).
2. J. C. J. Bart, *Acta Crystallogr., Sect. B* **24**, 1277–1287 (1968).
3. R. Weiss, B. Pormrehn, F. Hampel and W. Bauer, *Angew. Chem., Int. Ed. Engl.* **34**, 1319–1321 (1995).
4. D. Gust, *J. Am. Chem. Soc.* **99**, 6980–6982 (1977).
5. D. Gust and A. Patton, *J. Am. Chem. Soc.* **100**, 8175–8181 (1978).
6. H. Pepermans, R. Willem, M. Gielen and C. Hoogzand, *J. Org. Chem.* **51**, 301–306 (1986).
7. H. Pepermans, R. Willem, M. Gielen and C. Hoogzand, *Magn. Reson. Chem.* **26**, 311–318 (1988).
8. R. Willem, M. Gielen, C. Hoogzand and H. Pepermans, in *Advances in Dynamic Stereochemistry*, edited by M. F. Gilen. Freund, London (1985). 207–285.
9. F. H. Cano and M. Martínez-Ripoll, *J. Mol. Struct. (Theochem)* **258**, 139–158 (1992).
10. K. Mislow, D. Gust, P. Finocchiaro and R. Boettcher, *Top. Curr. Chem.* **47**, 1–28 (1974); J. Brocas, M. Gielen and R. Willem, *The Permutational Approach to Dynamic Stereochemistry*. McGraw-Hill, New York (1983).
11. R. M. Claramunt, D. Sanz, J. Catalán, F. Fabero, N. A. García, C. Foces-Foces, A. L. Llamas-Saiz and J. Elguero, *J. Chem. Soc., Perkin Trans. 2* 1687–1699 (1993).
12. P. Molina, A. Arqués, R. Obón, A. L. Llamas-Saiz, C. Foces-Foces, R. M. Claramunt, C. López and J. Elguero, *J. Phys. Org. Chem.* **5**, 507–517 (1992).
13. R. N. Henrie, II, and W. H. Yeager, *Heterocycles* **35**, 415–426 (1993).
14. A. Altomare, M. C. Burla, M. Camalli, G. Cascarano, C. Giacovazzo, A. Guagliardi and G. Polidori, *J. Appl. Crystallogr.* 435–435 (1994).
15. J. M.Stewart, P. A. Machin, C. W. Dickinson, H. L. Ammon, H. Heck and H. Flack, *The X-Ray System*, Technical Report TR-446. Computer Science Center, University of Maryland (1976).
16. *International Tables for X-Ray Crystallography*, Vol. IV. Kynoch Press, Birmingham (1974).
17. *AMPAC Version 5.0*. Semichem, Shawnee, KS. (1994).
18. S. R. Hall, H. D. Flack and J. M. Stewart, *Xtal13.2*. University of Western Australia, Lamb, Perth (1994).