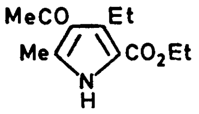
Crystallographic Studies in the Pyrrole Series. Part II.[1] Crystal and Molecular Structure of 5,5′-Diethoxycarbonyl-3,3′,4,4′-tetraethyldipyrrol-2-ylmethane

By **R. Bonnett**, **M. B. Hursthouse**, and **S. Neidle**,* Department of Chemistry, Queen Mary College, Mile End Road, London E1 4NS

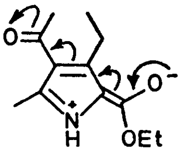
Crystals of the title compound (III) are monoclinic, space group $P2_1/c$, with cell dimensions a = 8·655(2), b = 17·781(4), c = 15·465(4) Å and β = 102·70(2)°. The structure was solved by direct methods and refined by block-matrix least-squares techniques to R 0·0713 for 2711 observed reflections. The pyrrole rings are distorted from the C_{2v} symmetry of pyrrole, but the distortion is much less marked than that found earlier with 3-acetyl-5-ethoxycarbonyl-4-ethyl-2-methylpyrrole (I). The two carbonyl groups of (III) are arranged in different orientations with respect to the N ··· H vectors, one *syn* and the other *anti*. The molecules are arranged in the crystal lattice as hydrogen-bonded, centrosymmetrically related dimers.

OUR previous studies[1] on the monopyrrole (I) have shown that it exists, at least in the solid state, with a perturbed bonding arrangement in the ring, which is thought to reflect the importance of dipolar structures such as (II). The ester carbonyl group of (I) is in an *anti*-conformation [as shown in (II)] with respect to the N–H bond, and the structural evidence clearly indicates that only intermolecular hydrogen bonding is important in the crystal lattice.

We have determined the crystal and molecular structure of the title compound (III) for several reasons.



(I)



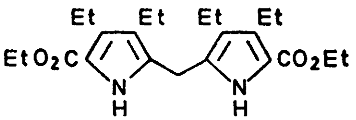
(II)

(i) It has no β-carbonyl group to stabilise the dipolar structure [(II), arrows] so that any effect on the ring

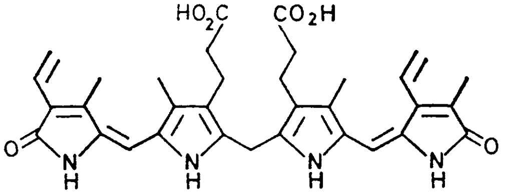
---

[1] Part I, R. Bonnett, M. B. Hursthouse, and S. Neidle, *J.C.S. Perkin II*, 1972, 902.

geometry would thus be solely due to the carbonyl function of the α-ester group. (ii) It is not clear whether the rotational isomerism of the carbonyl group in this type of compound is dependent on the hydrogen-bonding situation in the lattice, and whether there is indeed a preferred conformation at all.[2] An X-ray study, in conjunction with the infrared data, could possibly give an answer to this question. (iii) The dipyrromethane system is regarded as a useful model for certain bile pigments,[3] and particularly for bilirubin (IV), with regard to the relative orientations of the two rings around the central methylene bridge.



(III)



(IV)

EXPERIMENTAL

Crystals of (III) were obtained from ethanol.

Crystal Data.—$C_{23}H_{34}N_2O_4$, M = 402·0, Monoclinic, a = 8·655(2), b = 17·781(4), c = 15·465(4) Å, β = 102·70(2)°, U = 2321·8 Å^3, D_m = 1·16(2) (by flotation), Z = 4, D_c = 1·150, $F(000)$ = 872·0. Space group $P2_1/c$ (No. 14, C^5_{2h}) from systematic absences: $h0l$, $0k0$ for l, $k = 2n$. Cu-K_α radiation, λ = 1·54178 Å; μ(Cu-K_α) = 6·39 cm^{-1}.

Cell dimensions were obtained from diffractometer measurements of 2θ values

Intensity data were collected for a crystal of dimensions *ca.* 0·50 × 0·25 × 0·30 mm, mounted about the b^* axis, by use of a General Electric XRD 6 diffractometer, equipped with a manual goniometer, pulse-height analyser, and scintillation counter. Nickel-filtered copper radiation was used. The stationary-crystal–stationary-counter mode of intensity estimation was employed throughout, with a 4° take-off angle, and a counting time of 10 s. Individual backgrounds at $(2\theta_{hk} + 1)°$ were measured for all reflections. The 204 and 080 reflections were used as reference reflections in order to check on crystal stability. There was no significant alteration in the measured intensity for either reflection during the data collection.

The intensities of 3436 independent reflections were measured, to a limit of 120° in 2θ. Of these, 2711 were considered to be significantly above background, having net counts $> 3\sigma(I)$. $\sigma(I)$, the standard deviation in the intensity[4] was taken as $[I + 2B + (0{\cdot}03I)^2]^{\frac{1}{2}}$, where B is the background count. The 723 'unobserved' reflections were excluded from the least-squares calculations in the refinement of the structure.

No correction for absorption was applied as its effects were considered to be negligible.

Structure Solution and Refinement.—The structure was solved by re-iterative application of the Sayre equation, by use of the program REL.[5] The 151 highest E values, as determined from a Wilson plot, were input to the program, which automatically chose a set of origin-determining reflections, together with four other, initially symbolic, phases. One of the 16 phase sets converged with the least number of iterations, and had the highest consistency index,[5] 0·904. 149 out of the 151 phases were determined in this set with a probability of >0·99, and were then used in the calculation of an E-map. It clearly showed 27 out of the 29 atom positions in the molecule. A structure-factor calculation with these 27 positions assigned to carbon atoms, followed by three cycles of full-matrix least-squares refinement, gave R 0·264. A subsequent difference-Fourier synthesis revealed the two remaining atoms in their expected positions. These were both terminal chain carbon atoms, with appreciable thermal motion. Three cycles of least-squares refinement with all the 29 atoms now included with their correct scattering factors, reduced R to 0·158. Conversion of the isotropic thermal parameters to their anisotropic β_{ij} equivalents, followed by four more least-squares cycles, gave R 0·121. All the hydrogen atom positions were deduced from a difference-Fourier map, and their inclusion in the structure-factor calculations reduced R to 0·088. Final refinement was performed on blocks of 12 non-hydrogen atoms (with anisotropic temperature factors) and 15 hydrogen atoms (with isotropic temperature factors) at a time, until the parameter shifts were all $<0{\cdot}1\sigma$. This procedure was

TABLE 1

Final positional parameters for the non-hydrogen atoms, as fractions of the unit-cell edges with estimated standard deviations in parentheses

Atom	x	y	z
C(1)	0·4927(4)	0·3502(2)	0·5266(2)
C(2)	0·5399(4)	0·2806(2)	0·5642(2)
C(3)	0·6256(4)	0·2942(2)	0·6518(2)
C(4)	0·6280(4)	0·3714(2)	0·6656(2)
C(5)	0·7043(4)	0·4177(2)	0·7444(2)
C(6)	0·8748(4)	0·4358(2)	0·7482(2)
C(7)	1·0142(4)	0·4114(2)	0·8036(2)
C(8)	1·1413(4)	0·4458(2)	0·7752(3)
C(9)	1·0772(4)	0·4904(2)	0·7036(2)
N(10)	0·5461(3)	0·4047(1)	0·5904(2)
N(11)	0·9131(3)	0·4839(2)	0·6869(2)
C(12)	0·4061(4)	0·3747(2)	0·4411(2)
O(13)	0·3719(3)	0·3185(1)	0·3818(2)
C(14)	0·2992(5)	0·3410(2)	0·2908(3)
C(15)	0·2828(5)	0·2706(3)	0·2355(3)
O(16)	0·3666(3)	0·4399(1)	0·4225(2)
C(17)	0·5055(4)	0·2047(2)	0·5213(3)
C(18)	0·6298(6)	0·1833(2)	0·4675(3)
C(19)	0·6964(4)	0·2358(2)	0·7194(3)
C(20)	0·8604(5)	0·2104(3)	0·7109(3)
C(21)	1·0266(5)	0·3580(2)	0·8810(3)
C(22)	1·0518(6)	0·3981(3)	0·9701(3)
C(23)	1·3160(4)	0·4367(2)	0·8149(3)
C(24)	1·3862(5)	0·5050(3)	0·8699(3)
C(25)	1·1535(5)	0·5369(2)	0·6477(3)
O(26)	1·0452(3)	0·5740(2)	0·5863(2)
C(27)	1·1075(6)	0·6220(3)	0·5251(3)
C(28)	0·9609(3)	0·6620(3)	0·4712(3)
O(29)	1·2945(3)	0·5434(2)	0·6554(2)

---

[2] R. A. Jones, *Adv. Heterocyclic Chem.*, 1970, **11**, 456.

[3] T. With, 'Bile Pigments,' Academic Press, New York, 1968.

[4] R. H. Eisenberg and J. A. Ibers, *Inorg. Chem.*, 1966, **5**, 411.

[5] R. E. Long, Ph.D Thesis, University of California, Los Angeles, 1965.

necessitated in view of the limited capacity of the full-matrix least-squares program available. The $10\bar{2}$ and $20\bar{2}$ reflections were omitted from the refinement because of suspected extinction, and a Hughes-type[6] weighting scheme was used with $\sqrt{w} = 1$ for $F_o < F^*$ and $\sqrt{w} = F^*/F_o$ for $F_o > F^*$, with F^* set at 80·0. The final R for the 2711 observed reflections was 0·0713, and 0·0738 for the 3434 recorded.

TABLE 2

Final anisotropic thermal parameters ($\times 10^4$) * for the non-hydrogen atoms with standard deviations in parentheses

Atom	β_{11}	β_{22}	β_{33}	β_{12}	β_{13}	β_{23}
C(1)	140(5)	28(1)	52(2)	1(2)	11(3)	2(1)
C(2)	137(5)	27(1)	55(2)	−2(2)	22(3)	0(1)
C(3)	147(6)	29(1)	59(2)	2(2)	27(3)	4(1)
C(4)	134(5)	27(1)	56(2)	−3(2)	26(3)	2(1)
C(5)	147(6)	32(1)	55(2)	−4(2)	22(3)	−1(1)
C(6)	150(6)	27(1)	51(2)	1(2)	22(3)	−2(1)
C(7)	153(6)	27(1)	59(2)	0(2)	11(3)	−2(1)
C(8)	150(6)	26(1)	66(2)	1(2)	13(3)	−2(1)
C(9)	137(6)	28(1)	62(2)	−4(2)	23(3)	−1(1)
N(10)	142(5)	24(1)	55(2)	−3(2)	12(3)	4(1)
N(11)	128(4)	28(1)	51(1)	−1(2)	15(2)	2(1)
C(12)	129(5)	32(1)	60(2)	−3(2)	8(3)	3(1)
O(13)	211(5)	28(1)	59(1)	4(2)	−4(2)	−2(1)
C(14)	254(8)	41(2)	63(2)	13(3)	−15(4)	−2(2)
C(15)	221(8)	55(2)	63(3)	−1(3)	20(4)	−11(2)
O(16)	176(4)	27(1)	65(2)	6(2)	−1(2)	4(1)
C(17)	173(6)	27(1)	70(2)	−2(2)	30(3)	−2(1)
C(18)	294(10)	44(2)	81(3)	8(3)	65(4)	−12(2)
C(19)	170(6)	32(1)	63(2)	5(2)	26(3)	10(1)
C(20)	193(7)	51(2)	82(3)	25(3)	31(4)	21(2)
C(21)	211(7)	35(1)	59(2)	3(3)	5(3)	7(1)
C(22)	380(12)	57(2)	60(3)	−14(4)	34(4)	2(2)
C(23)	155(6)	36(2)	85(3)	2(2)	−9(3)	3(2)
C(24)	224(9)	45(2)	101(3)	−11(3)	−24(4)	−6(2)
C(25)	188(7)	34(1)	71(3)	−8(3)	38(3)	−2(2)
O(26)	200(5)	41(1)	64(2)	−9(2)	39(2)	10(1)
C(27)	296(10)	58(2)	68(3)	−22(4)	57(4)	15(2)
C(28)	393(13)	63(3)	86(3)	−14(5)	50(5)	26(2)
O(29)	171(5)	65(2)	102(2)	−21(2)	49(3)	0(1)

* The thermal parameters are defined by the equation: $f_i = F_i^0 \exp -(\beta_{11}h^2 + \beta_{22}k^2 + \beta_{33}l^2 + 2\beta_{12}hk + 2\beta_{13}hl + 2\beta_{23}kl)$.

The final positional and thermal parameters for the atoms are listed in Tables 1—3. Supplementary Publication No. SUP 20401 (6 pp., 1 microfiche), lists the final observed and calculated structure factors.*

The atomic scattering factors used were taken from ref. 7*a* for non-hydrogen atoms, and from ref. 7*b* for hydrogen.

All calculations were performed on the University of London CDC 6600 computer, using the '*X*-Ray '70' computing system,[8] except where otherwise stated.

DISCUSSION

TABLE 3

Final positional and isotropic thermal for the hydrogen atoms, with estimated standard deviations in parentheses

Atom	x	y	z	B/Å^2
H(1,5)	0·644(5)	0·470(2)	0·741(3)	3·3(1)
H(2,5)	0·711(5)	0·389(3)	0·799(3)	4·4(1)
H(3,10)	0·546(6)	0·458(3)	0·576(3)	6·0(1)
H(4,11)	0·821(6)	0·509(3)	0·643(4)	5·0(2)
H(5,14)	0·194(7)	0·364(3)	0·293(4)	3·4(2)
H(6,14)	0·377(7)	0·390(3)	0·264(4)	9·3(2)
H(7,15)	0·232(7)	0·287(4)	0·176(4)	8·6(2)
H(8,15)	0·205(6)	0·233(3)	0·262(3)	6·2(1)
H(9,15)	0·398(8)	0·235(4)	0·247(4)	11·6(2)
H(10,17)	0·496(5)	0·164(3)	0·571(3)	4·2(1)
H(11,17)	0·387(6)	0·202(3)	0·482(3)	4·6(1)
H(12,18)	0·622(7)	0·299(4)	0·414(4)	8·6(2)
H(13,18)	0·614(8)	0·126(4)	0·444(5)	11·6(2)
H(14,18)	0·609(9)	0·185(4)	0·501(5)	12·6(2)
H(15,19)	0·635(7)	0·183(3)	0·710(4)	8·5(2)
H(16,19)	0·727(7)	0·256(3)	0·784(4)	6·4(2)
H(17,20)	0·897(6)	0·177(3)	0·760(4)	5·5(1)
H(18,20)	0·857(7)	0·182(4)	0·644(4)	10·8(2)
H(19,20)	0·916(7)	0·263(4)	0·717(4)	9·0(2)
H(20,21)	1·128(7)	0·319(3)	0·822(4)	8·7(2)
H(21,21)	0·918(5)	0·331(3)	0·869(3)	4·1(1)
H(22,22)	0·953(6)	0·434(3)	0·961(3)	5·7(1)
H(23,22)	1·156(7)	0·436(3)	0·982(4)	8·0(2)
H(24,22)	1·044(7)	0·365(3)	1·019(4)	6·7(2)
H(25,23)	1·327(7)	0·395(3)	0·856(4)	3·5(2)
H(26,23)	1·367(8)	0·422(4)	0·762(4)	12·2(2)
H(27,24)	1·325(7)	0·512(4)	0·922(4)	7·2(2)
H(28,24)	1·363(6)	0·547(3)	0·834(4)	5·9(2)
H(29,24)	1·506(7)	0·495(3)	0·901(4)	7·1(2)
H(30,27)	1·167(7)	0·583(4)	0·497(4)	8·2(2)
H(31,27)	1·195(7)	0·664(4)	0·567(4)	8·6(2)
H(32,28)	0·890(6)	0·624(3)	0·434(3)	4·8(1)
H(33,28)	0·997(8)	0·685(4)	0·432(4)	9·7(2)
H(34,28)	0·914(7)	0·697(3)	0·516(4)	9·7(2)

The mean C–H bond length is 1·05(16) Å. The digits after the comma in each hydrogen atom number refer to the atom to which it is bonded.

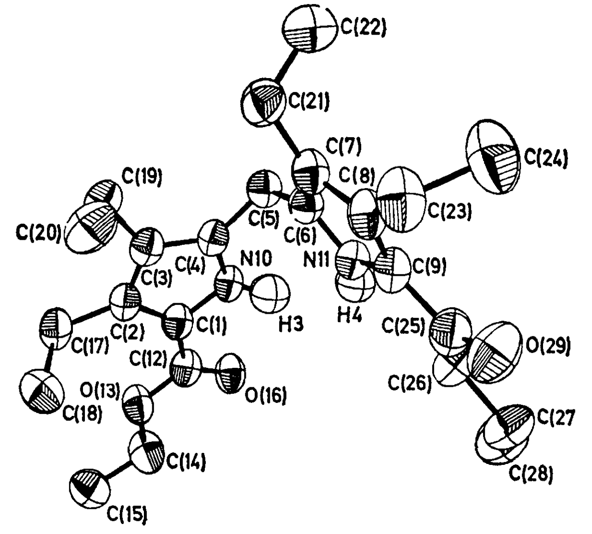


FIGURE 1 The conformation of the molecule, with the atomic numbering used. The thermal ellipsoids are scaled to include 50% probability

The structure of 5,5′-diethoxycarbonyl-3,3′,4,4′-tetraethyldipyrrol-2-ylmethane (III) is shown in Figure 1[9] which also shows the arbitrary crystallographic numbering scheme which will be used in the subsequent discussion. Figures 2 and 3 give the bond lengths and angles in the molecule; the standard deviations are

---

* For details of Supplementary Publications see Notice to Authors No. 7 in *J. Chem. Soc.* (*A*), 1970, Issue No. 20 (items less than 10 pp. are sent as full size copies).

[6] E. W. Hughes, *J. Amer. Chem. Soc.*, 1941, **63**, 1737.

[7] (*a*) 'International Tables for *X*-Ray Crystallography,' vol. III, Kynoch Press, Birmingham, 1962; (*b*) R. F. Stewart, E. R. Davidson, and W. T. Simpson, *J. Chem. Phys.*, 1965, **42**, 3175.

[8] A revision (1970) of '*X*-Ray '67,' Program System for *X*-Ray Crystallography, University of Maryland Technical Report, 67 58, 1967.

[9] C. K. Johnson, ORTEP, ORNL 3794, Oak Ridge National Laboratory, 1965.

probably underestimates because of the block-diagonal least-squares approximation used in the refinement.

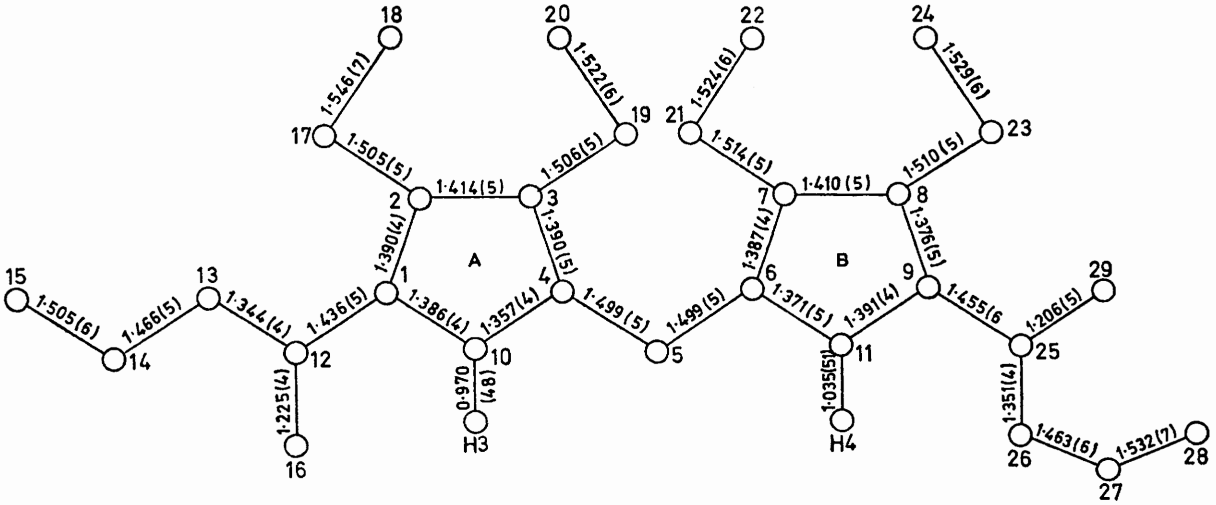


FIGURE 2 Intramolecular bond lengths with estimated standard deviations in parentheses

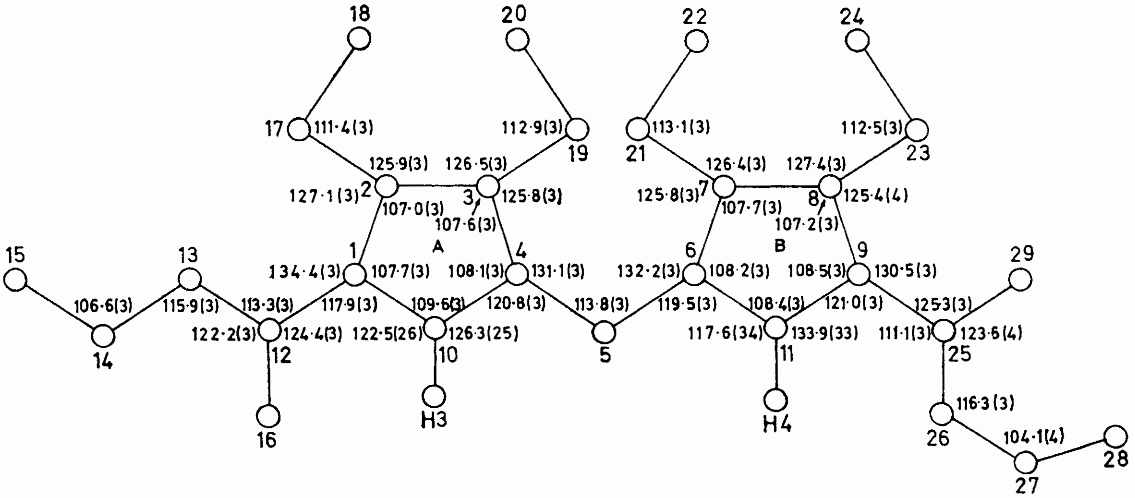


FIGURE 3 Intramolecular valence angles (deg.) with estimated standard deviations in parentheses

The pyrrole rings in (III) are virtually equivalent with respect to bond lengths and angles. In Table 4 these bond lengths are compared with those found for pyrrole itself[10] and for compound (I).[1] Evidently, although the rings in (III) are distorted in the same sense as is found in compound (I), the effect is much smaller; as before this deviation from C_{2v} symmetry, which is marginally more marked in ring A, is ascribed to the contribution of dipolar canonical forms such as (V). It is clear that in compound (I) the β-carbonyl group has a significant effect in reinforcing this distortion [*cf.* (II), arrows]. However, the C(3)–C(4) bonds in (I) and (III) do not appear to acquire additional double-bond character relative to the C(3)–C(4) bond of pyrrole itself.

Both pyrrole rings are planar (interplanar angle 71·9°), and have their respective carbonyl substituents lying close to these planes (Table 5). Thus the carbonyl group at C(1) lies only 5·6° out of the plane of ring A, and the corresponding angle for ring B and its carbonyl group is 2·3°. Both these arrangements favour carbonyl–ring conjugation through the C(1)–C(12) and C(9)–C(25) single bonds, which are shortened by 0·044 Å (9σ) and 0·025 Å (4σ), respectively, from the single (C_{sp^2}–C_{sp^2}) bond length of 1·48 Å.[11] Ring A has the larger interaction, as well as a slightly greater ring distortion, which implies that the dipolar canonical form, *e.g.* (V), is more important for ring A than for ring B. This may be related to the remarkable finding that the ester functions on rings A and B take up different conformations in the solid state; in ring A the carbonyl takes up a *syn*-arrangement with respect to the N · · · H vector, whilst in ring B it is *anti* (Figure 1). I.r. studies [2] have suggested

---

[10] L. Nygaard, J. T. Nielson, J. Kirchheimer, G. Maltesen, J. Rastrup-Anderson, and G. O. Sorensen, *J. Mol. Structure*, 1969, **3**, 491.

[11] *Chem. Soc. Special Publ.*, No. 18, 1965.

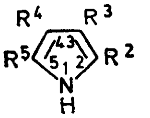
that such rotational isomers of 2-ethoxycarbonylpyrroles have *K ca.* 1 in solution; we think that the arrangement in the solid is probably determined by hydrogen-bonding requirements (see later).

TABLE 4

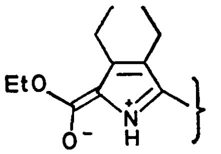
Bond lengths (Å) for the pyrrole ring in various systems

		Compound (III) [b]		
Bond	Pyrrole [a]	Ring A (*syn*)	Ring B (*anti*)	Compound (I) [c]
N(1)–C(2)	1·370	1·386	1·391	1·330
N(1)–C(5)	1·370	1·357	1·371	1·395
C(2)–C(3)	1·382	1·390	1·376	1·382
C(4)–C(5)	1·382	1·390	1·387	1·404
C(3)–C(4)	1·417	1·414	1·410	1·417

[a] $R^2 = R^3 = R^4 = R^5 = H$; from ref. 10. [b] $R^2 = CO_2Et$, $R^3 = R^4 = Et$, $R^5 = CH_2R$. [c] $R^2 = CO_2Et$, $R^3 = Et$, $R^4 = COMe$, $R^5 = Me$; from ref. 1.



The various substituents display their usual geometries, except that the C_{sp^3}–C_{sp^3} bonds of the ethyl groups are shortened. This is a commonly observed effect (*e.g.* in 5-ethyl- and 5-ethyl-5-hydroxy-barbituric acid [12]) and is ascribed to the neglect of the relatively large thermal motion of the terminal carbon atoms. The four terminal carbon atoms of the β-ethyl groups are mutually arranged so as to minimise both intra- and inter-molecular hydrogen–hydrogen repulsions. Thus, none of the hydrogen atoms are closer than 3·2 Å. The ethyl groups [C(2), C(17), C(18)], [C(3), C(19), C(20)], [C(7), C(21), C(22)], and [C(8), C(23), C(24)], are twisted by angles of 85·8, 83·7, 80·8, and 75·6° out of the planes of their respective rings.



(V)

Hydrogen Bonding.—The molecules are arranged in the crystal lattice so as to form hydrogen-bonded dimers, related by a centre of symmetry (Figure 4). These dimers are compact in shape and allow quite efficient packing. A similar arrangement has been suggested for pyrroles with α-carbonyl groups, on the basis of a number of physicochemical and spectroscopic investigations,[2] both in the liquid and solid states. Many purine and pyrimidine bases have been found to form analogous hydrogen-bonded pairs in the solid state.[13]

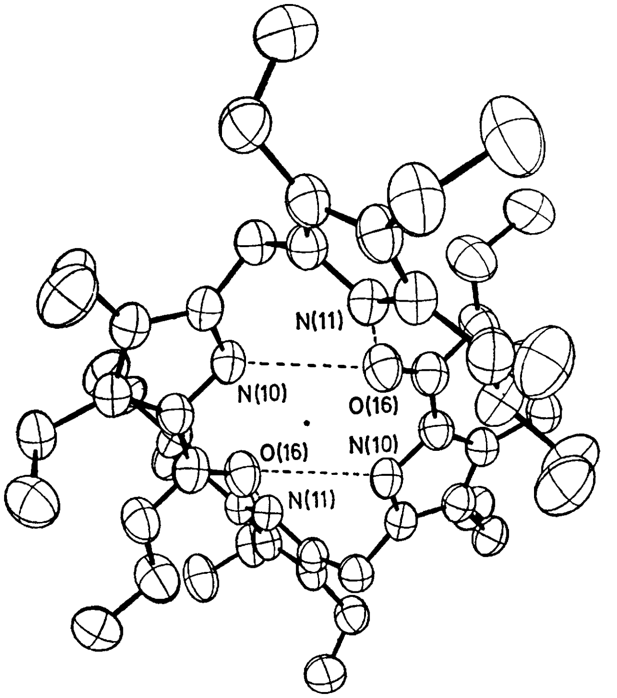


FIGURE 4 (100) Projection of the hydrogen-bonded dimer; the two molecules are related by the centre of symmetry shown. Dashed lines indicate hydrogen bonds

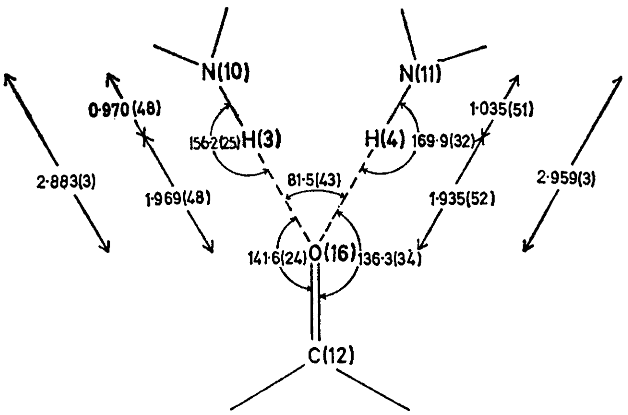


FIGURE 5 Schematic diagram of the hydrogen bonding with distances (Å) and angles (deg.)

Figure 5 shows the geometry of the interaction in more detail. The O(16) carbonyl of one molecule associates with both the imino-hydrogens from the other molecule, and the O(29) carbonyl is not involved at all. The i.r. spectrum shows two distinct C=O bands at 1693 and 1653 cm^{-1} (KBr disc). Both hydrogen bonds fall well within the accepted range for N ··· O distances of 2·73—3·09 Å,[13,14] as do the oxygen–hydrogen distances. The deviations from their idealised values of the angles involved at the hydrogen and oxygen atoms are in agreement with the conclusion of Donohue [14] that bent hydrogen bonds are commonly found. The N–H donors are symmetrically arranged out of the plane defined by C(1), C(12), O(13), and O(16) [plane (3), Table 5]. This

---

[12] B. M. Gatehouse and B. M. Craven, *Acta Cryst.*, 1971, *B*, **27**, 1337.

[13] D. Voet and A. Rich, *Progr. Nucleic Acid Res.*, 1970, **10**, 183.

[14] J. Donohue, in 'Structural Chemistry and Molecular Biology,' eds. A. Rich and N. Davidson, Freeman, San Francisco, 1968.

is also a commonly observed situation,[14] *e.g.* in cytosine,[15] with the two nitrogens 0·70 and −2·04 Å out of the carbonyl group plane.

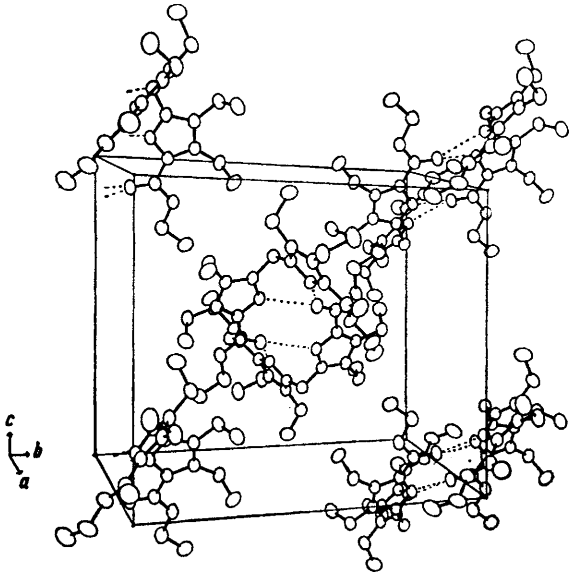


FIGURE 6 The packing in the crystal lattice. Dashed lines indicate hydrogen bonds

TABLE 5

Equations of least-squares planes through various parts of the molecule in the form $px + qy + rz = s$ where x, y, and z are the fractional unit-cell co-ordinates. Deviations (Å) of atoms from the planes are listed in square brackets

	p	*q*	*r*	*s*
Plane (1): C(1)—(4), N(10)	−8·15	−1·28	8·15	−0·17
[C(1) −0·006, C(2) 0·003, C(3) 0·001, C(4) −0·005, N(10) 0·007, C(12) −0·028, O(16) 0·058, C(17) 0·032, C(19) 0·049, C(5) −0·044]				
Plane (2): C(6)—(9), N(11)	1·52	13·69	9·85	12·00
[C(6) 0·001, C(7) 0·001, C(8) −0·002, C(9) 0·002, N(11) −0·002, C(5) −0·024, C(21) 0·013, C(23) 0·001, C(25) −0·028, O(29) −0·077]				
Plane (3): C(1), C(12), O(13), O(16)	8·19	2·86	−7·45	1·11
[C(1) 0·000, C(12) −0·001, O(13) 0·000, O(16) 0·00; N(10) * 1·202, N(11) * −1·454, H(3,10) * 0·979, H(4,11) * −1·035]				
Plane (4): C(9), C(25), O(26), O(29)	−1·09	13·58	9·97	12·50
[C(9) 0·002, C(25) −0·008, O(26) 0·002, O(29) 0·003]				

* Atoms in the centro-symmetrically related molecule.

Figure 6 shows the packing of the dimers in the lattice. There are no hydrogen bonds present other than those already mentioned, and no unusually short intermolecular distances. It seems that the *syn–anti*-arrangement of the two carbonyl groups is dictated by the tendency of the crystal packing to form the most energetically favourable hydrogen-bonding scheme, and that this is responsible for the relative orientation of the two rings at an angle of 71·9° to each other.

The award of an I.C.I. Research Fellowship (to S. N.) is gratefully acknowledged.

[2/351 *Received, February 17th,* 1972]

---

[15] D. L. Barker and R. E. March, *Acta Cryst.*, 1964, **17**, 1581.