Crystal and Molecular Structure of a Photoisomer of an Oxodipyrromethene: The *E*-Isomer of 3,4-Dimethyl-2,2′-pyrromethen-5(1*H*)-one

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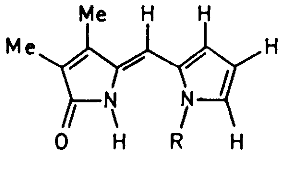
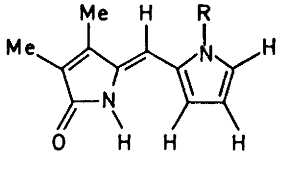
The structure of the *E*-isomer of an oxodipyrromethene, 3,4-dimethyl-2,2′-pyrromethen-5(1*H*)-one, $C_{11}H_{12}N_2O$, has been determined. This was obtained by photoisomerization from the *Z*-isomer. It crystallizes in the monoclinic space group $P2_1/a$ with a = 10.479(3), b = 8.643(2), c = 11.926(2) Å, β = 114.07(1)°, Z = 4. The structure was solved by direct methods and refined by full-matrix least-squares to an R factor of 0.064. The molecule is in an anticlinal conformation with a dihedral angle of 49.8° about the methine single bond. Each oxygen atom is hydrogen-bonded to two nitrogen atoms which are located on two different molecules. Bond lengths and angles are similar to those found in the *Z*-isomer.

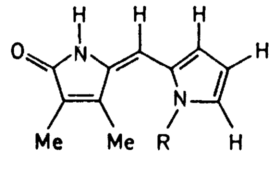
In bilirubin,[1] as in virtually all the bile pigments and other linear tetrapyrroles [2-9] studied thus far by *X*-ray crystallographic techniques, adjacent rings in the dipyrromethene moieties have the *Z*-configuration about the methine double bond and adopt the synperiplanar conformation at the methine single bond.† The same configuration and conformation have also been found for tripyrroles [11,12] and for several dipyrromethenes.[13-17] Only two examples of open-chain pyrroles with the antiperiplanar conformation have been reported.[9,14] The *E*-configuration has been reported in only two structures.[15] However in one case, 5-nitro-octaethylbiliverdin,[8] the presence of the nitrogen atom causes the configuration around C(4)–C(5) to be *Z* only because of an application of the Cahn–Ingold–Prelog sequence rules. The geometry of the two rings involved is the same as found in the present case, which has an *E*-configuration.



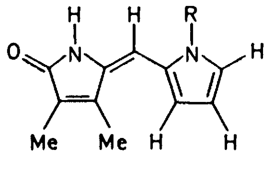
Z synperiplanar



Z antiperiplanar



E synperiplanar



E antiperiplanar

(I) R = H

(II) R = Me

Photochemistry has long been known to play an important part in the reactions of bile pigments. Photoisomerization has been observed in the bilitriene aetiobiliverdin IVγ and in some of its derivatives.[18] Studies have also been carried out on a number of oxodipyrromethenes which photoisomerize. Among the better characterized are 3,4-dimethyl-2,2′-pyrromethen-5(1*H*)-one (I) [19] and its *N*-methyl derivative (II).[20] For (I), the normal isomer is *Z*-synperiplanar. For (II) a *Z*-antiperiplanar isomer is obtained.[19] This work on model compounds in part helped to prove the existence of a ‘ photobilirubin ’, in which presumably photoisomerization takes place, breaking the extensive intramolecular hydrogen bonding, making bilirubin more water soluble and thus more easily excreted.[21]

We report here the structure of the *E*-isomer of (I) obtained by photoisomerization. It should provide interesting comparisons with the *Z*-isomer.

EXPERIMENTAL

The *E*-isomer of (I) was prepared using procedures based on previously published methods.[19,20] The *Z*-isomer of (I) (25.5 mg) was dissolved in methanol (150 ml) and irradiated with a sun lamp for 15 min. Nitrogen gas was bubbled through the ice-cooled solution. The *E*-isomer was isolated by t.l.c. (silica gel; $CHCl_3$–methanol 20 : 1). It was crystallized from a methanol solution, saturated with nitrogen gas, which was allowed to sit in the dark at 0 °C for one week.

The crystal chosen for intensity measurements was a yellowish parallelepiped with no well defined faces. The maximum dimension was *ca.* 0.6 mm. The crystal was lost before accurate dimensions were obtained. The crystal was mounted in a glass capillary at an arbitrary orientation.[22]

Cell dimensions were determined by least-squares calculations, minimizing the differences between observed and calculated 2θ (measured at both + and −2θ) for 25 reflections. Cell constant data and the subsequent intensity data were collected using Mo-K_β radiation (λ = 0.632 25 Å) on a Datex-Syntex automated diffractometer.

Crystal Data.—$C_{11}H_{12}N_2O$, M = 188.2. Monoclinic, a = 10.479(3), b = 8.643(2), c = 11.926(2) Å, β = 114.07(1)°,

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† This nomenclature is in accord with IUPAC nomenclature using the rules of naming conformers of Klyne and Prelog.[10] It is hoped that this nomenclature will be used more extensively in the future, replacing the not clearly defined *syn-* and *anti-* designations.

$U = 986$ Å^3, $D_c = 1.15$ g cm^{-3}. $Z = 4$. $\mu(\text{Mo-}K_\beta) = 0.614$ cm^{-1}. Systematic absences ($h0l$ for h odd, $0k0$ for k odd) uniquely determined the space group as $P2_1/a$, a non-standard aspect of $P2_1/c$ (C_{2h}^5, #14).

Intensity data were collected by the θ—2θ scan method, monitoring the intensity scale by remeasuring a group of five standard reflections periodically. The intensities of these standard reflections remained constant within $\pm 2\%$. Backgrounds at either end of the scan range were collected for half the scan time. The scan rate was 4° min^{-1} while the scan range was 3°. Independent reflections (1938) were measured out to a $\sin\theta/\lambda$ of 0.61 or 22.5 in θ. There were virtually no observable intensities at this limit, so data collection was not continued to higher values of 2θ. A total of 691 reflections had a net intensity $I \geqslant 3\sigma$ and were used in the analysis. The values of σ_I were those determined from counting statistics.

The intensities were not corrected for coincidence. No absorption correction was applied. Structure factors were calculated in the usual way assuming an ideally imperfect monochromator for the polarization factor.

Determination and Refinement of the Structure.—The structure was solved by an automatic multi-solution technique which is part of the SHELX-76 system of programs.[23] 2^{12} Sign permutations were expanded by the Σ_2 formula. All 14 non-hydrogen atoms were found in the subsequent E maps.

The structure was solved using programs on an Amdahl 470V/6 computer. Some other calculations were done on this computer using programs among those previously listed,[11] but most of the calculations were performed on a PDP 11/40 computer using the Enraf–Nonius structure determination package.[24] Use was also made of the PDP 11/40 Vector General graphics system.[25] The final refinements were performed at Brookhaven National Laboratory using programs listed elsewhere.[26]

In least-squares calculations, the function minimized was $\Sigma w(F_o - F_c)^2$. After some experimentation, it was clear that a unit weighting scheme ($w = 1$) would be the best choice, and this scheme was used throughout the refinement. Initially isotropic temperature factors were used, but in later refinement cycles, all non-hydrogen atoms were assumed to have anisotropic thermal motion. The positions of all 12 hydrogen atoms could be found on difference syntheses, but many of the observed bond parameters involving them were chemically unreasonable. Since the limited data precluded refinement of all the hydrogen atoms, only the parameters involving the imino hydrogen atoms were refined, assuming isotropic thermal motion. For the rest of the hydrogen atoms calculated positions were used in the structure factor calculations, but were not refined. A C–H distance of 1.0 Å and a thermal parameter, B, of 6.0 Å were assumed for these atoms.

After the final cycle, the shifts on all refined parameters were well below one standard deviation with the maximum shift/error ratio being 0.4. The final conventional R factor defined as $\Sigma||F_o| - |F_c||/\Sigma|F_o|$ was 0.064. The weighted R factor, R_w, defined as $\Sigma w||F_o| - |F_c||^2/\Sigma\, w\, F_o^2$ was 0.059. The error in an observation of unit weight, defined as $[\Sigma w||F_o| - |F_c||^2/(N_o - N_v)]^{\frac{1}{2}}$ was 1.23 for $N_o = 691$ reflections and $N_v = 135$ variables. A structure factor calculation with all reflections except those with $F_o = 0$ gave R and R_w values of 0.14 and 0.11, respectively. A final difference Fourier synthesis showed a maximum electron density of 0.17 eÅ^{-3}. No physical significance was attributed to this or any other peak in the final difference map.

No evidence of secondary extinction was found. Corrections for anomalous dispersion were not applied. Scattering factors were from ref. 27.

Final positional parameters are given in Table 1. Root mean square components of thermal displacement along the principal axes of thermal ellipsoids, thermal parameters, and observed and calculated structure factors are available as Supplementary Publication No. SUP 23144 (13 pp.).*

TABLE 1

Positional parameters derived from least-squares refinement [a]

Atom	X	Y	Z
O(1)	0.243 4(6)	0.311 5(6)	0.506 2(5)
N(1)	0.103 8(7)	0.101 1(8)	0.420 1(6)
N(2)	−0.292 8(6)	−0.238 7(8)	0.232 9(6)
C(1)	0.133 3(7)	0.253 5(9)	0.433 8(6)
C(2)	0.007 2(8)	0.330 9(9)	0.347 6(7)
C(3)	−0.092 3(7)	0.225 9(8)	0.287 8(6)
C(4)	−0.031 7(7)	0.073 9(9)	0.331 4(6)
C(5)	−0.084 2(7)	−0.071 9(9)	0.309 4(6)
C(6)	−0.212 3(7)	−0.124 1(9)	0.214 4(7)
C(7)	−0.275 9(8)	−0.091 4(10)	0.090 6(7)
C(8)	−0.392 3(9)	−0.185 2(11)	0.037 5(7)
C(9)	−0.402 1(8)	−0.274 1(11)	0.128 9(8)
C(10)	−0.000 5(9)	0.503 3(10)	0.337 2(8)
C(11)	−0.239 6(8)	0.259 5(9)	0.202 6(7)
H(N1)	0.161(6)	0.024(7)	0.446(6)
H(N2)	−0.274(6)	−0.271(7)	0.306(5)

[a] In Tables 1 and 2, the estimated standard deviation of least significant figures is shown in parentheses.

RESULTS AND DISCUSSION

An ORTEP [28] drawing of the structure is shown in Figure 1, together with the numbering scheme used as well as the nomenclature for the various types of carbon atoms. Figure 2 shows a stereoview of the molecule. From Figure 2 it can be seen that the molecule assumes what is most closely approximated as a E-configuration with an anticlinal conformation. A conversion from Z to E involves a rotation about the C(4)–C(5) bond, which

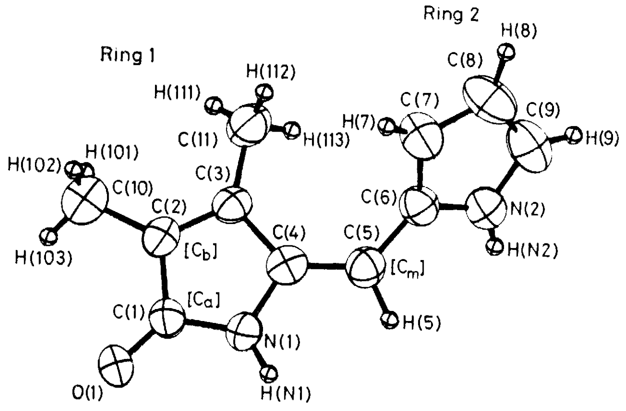

FIGURE 1 ORTEP [28] drawing of the structure of the E-isomer of (1). The numbering scheme is shown. The thermal ellipsoids are drawn for 30% probability. Also given in brackets is the nomenclature for different types of carbon atoms

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* See notice to Authors No. 7 in *J. Chem. Soc., Perkin Trans. 2*, 1980, Index Issue.

is essentially a double bond. A conversion of conformers involves rotation about C(5)–C(6), which is essentially a single bond. Unlike the *Z*-isomers of oxodipyrromethenes previously reported,[13,14] this compound is markedly non-planar. The dihedral angle at the methine single bond is 49.8° as compared to angles of 4—10° in the *Z*-isomers. The reason for this non-planarity is clear. A planar structure would bring the 11-methyl group and H(7) into impossibly close contact. In contrast the *E*-isomer of 5′-ethoxycarbonyl-3,4-dihydro-3′,4′-dimethyl-2,2′-pyrromethen-5(1*H*)-one (III) is planar.[15] This compound is similar to (I) except that the C_α–C_β bond in ring 1 is saturated. The methyl groups are on ring 2 which means there is no severe steric hindrance for the *E*-isomer. The *Z*-isomer of (III), which would be subject to the same sort of steric constraints as (I), is twisted, having an anticlinal conformation.

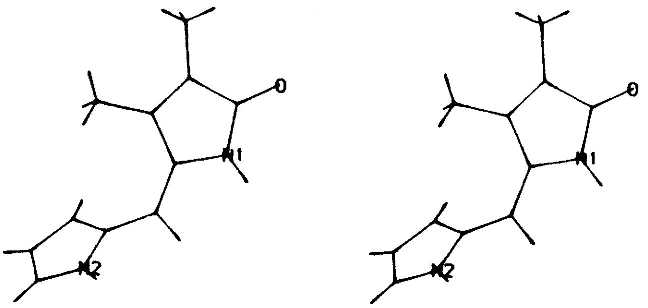
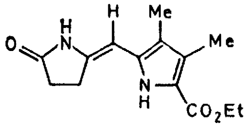
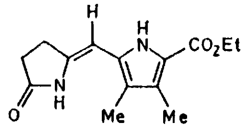


FIGURE 2 Stereoview of the structure of the *E*-isomer of (I)



(III) *E*-synperiplanar



(III) *Z*-anticlinal (shown in projection)

It is of interest to note that in polar solvents, the *Z*-isomer of (I) forms monomers which are believed to be non-planar. Lanthanide shift experiments suggest that the optimum value for the angle between the pyrrole rings is *ca.* 40°.[19,20] In non-polar solvents, the molecules are planar, probably because of the formation of hydrogen-bonded dimers.

The individual pyrrole rings are planar. The maximum deviation of an atom in a ring from the least-squares plane of that ring is 0.01 Å.

In the earlier studies on the *Z*-isomers of oxodipyrromethenes,[13,14] the conformation could be easily predicted. The choice of a synperiplanar conformation for (I) and an antiperiplanar conformation for (II) would minimize steric effects, allow a planar structure, and in the case of (I), maximize the possibilities for hydrogen-bonding. The other possibilities would lead to steric interactions between an imino-hydrogen atom and a methyl group. In the case of the *E*-isomer, any conformation would cause such steric interactions. No conformation could be planar. The observed choice of conformation probably rests on other factors, most likely hydrogen bonding and crystal packing effects. Indeed hydrogen bonding is suggested as the reason for the non-planarity of the *N*-ethyl derivative of (III),[15] which has an *E*-configuration and a synperiplanar conformation. The dihedral angle about the methine single bond is 150.9°. Instead of the hydrogen-bonded dimers between centrosymmetrically related molecules as found in the *Z*-isomers of (I) and (II), a much more complicated hydrogen bonding scheme exists in the present case. A stereoview of the packing is shown in Figure 3. Each oxygen atom is hydrogen bonded to nitrogen atoms on two different molecules.

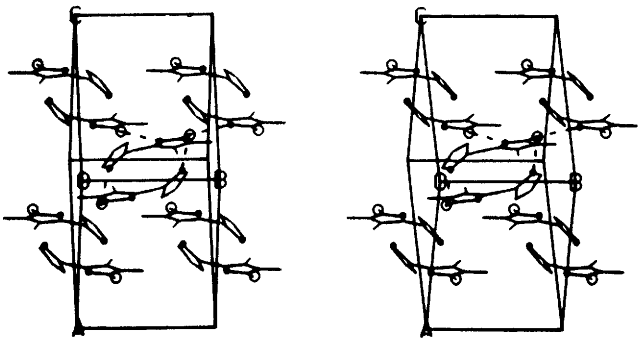


FIGURE 3 Stereoview of the packing in the unit cell, illustrating the hydrogen bonding scheme. Hydrogen bonds are denoted by dashed lines. Oxygen and nitrogen atoms are indicated by large and small circles respectively

The O(1) • • • N(1)′ distance is 2.90 Å [O(1) • • • H(N1)′ 1.97 Å] while the O(1) • • • N(2)″ distance is 3.01 Å [O(1) • • • H(N2)″ 2.19 Å]. The prime superscripts refer to the molecule related to reference molecule by the symmetry operation $x' = \frac{1}{2} - x$, $y' = \frac{1}{2} + y$, $z' = 1 - z$. The double prime superscripts refer to the molecule generated by the symmetry operations $x'' = -x$, $y'' = -y$, $z'' = 1 - z$.

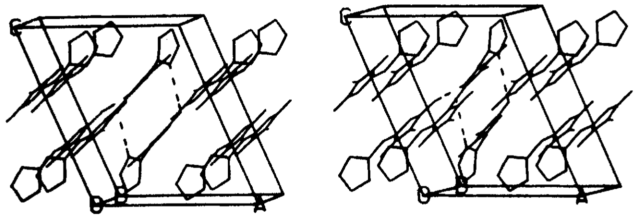


FIGURE 4 Another stereoview of the packing in the unit cell, illustrating the parallel packing of layers of ring 1. Hydrogen bonds between layers are shown by dashed lines

The molecules pack in layers in the unit cell so that the planes of ring 1 are parallel. This can be seen in Figure 4. The separation between planes is 3.2 Å. The O(1) • • • H(1)–N(1) hydrogen bonds join the layers.

Bond lengths and angles are given in Table 2. Many of the trends observed in the *Z*-isomers[13,14] are also found in the *E*-isomer. As usual for open-chain polypyrroles there is a considerable degree of bond fixation.

It is clear that the resonance form shown in (I) and (II) predominates.

Ring 1 is a pyrrolenone moiety. It is primarily present as the lactam form. This is the most predominant form in this type of compounds, as indicated by evidence both from *X*-ray diffraction data and from *X*-ray photoelectron spectroscopy.[29] The C–C bond in ring 1 is essentially a double bond. As has been observed in the *Z*-isomers, the N(1)–C(1) distance is shorter than the N(1)–C(4) distance. In ring 2 the N(2)–C(6) bond length is longer than the N(2)–C(9) distance. Both these differences are approximately 3σ, the first slightly above, the second slightly below this generally recognized criterion for significance. If these differences are significant, they indicate a degree of delocalization over the entire molecule not found in bilirubin [1] or mesobilirubin.[2] Further evidence for this delocalization is seen in ring 2, where the C_b–C_b distance is shorter than expected for a pyrrole ring. In addition the C(4)–C(5) bond length is longer than expected for a pure double bond, while the C(5)–C(6) distance is shorter than expected for a pure single bond.

TABLE 2

Bond lengths (Å) and angles (°)

O(1)–C(1)	1.232(8)	C(1)–N(1)–C(4)	111.5(7)
N(1)–C(1)	1.348(9)	C(6)–N(2)–C(9)	111.5(7)
N(1)–C(4)	1.402(8)	O(1)–C(1)–N(1)	125.9(7)
N(2)–C(6)	1.376(9)	O(1)–C(1)–C(2)	128.7(7)
N(2)–C(9)	1.336(9)	N(1)–C(1)–C(2)	105.3(6)
C(1)–C(2)	1.463(9)	C(1)–C(2)–C(3)	110.2(6)
C(2)–C(3)	1.346(9)	C(1)–C(2)–C(10)	121.1(7)
C(2)–C(10)	1.495(10)	C(3)–C(2)–C(10)	128.6(7)
C(3)–C(4)	1.459(10)	C(2)–C(3)–C(4)	106.7(6)
C(3)–C(11)	1.491(9)	C(2)–C(3)–C(11)	126.3(7)
C(4)–C(5)	1.357(10)	C(4)–C(3)–C(11)	126.7(7)
C(5)–C(6)	1.431(9)	N(1)–C(4)–C(3)	106.1(7)
C(6)–C(7)	1.379(9)	C(3)–C(4)–C(5)	133.2(6)
C(7)–C(8)	1.383(10)	N(1)–C(4)–C(5)	120.5(6)
C(8)–C(9)	1.372(11)	C(4)–C(5)–C(6)	128.4(7)
		C(5)–C(6)–N(2)	122.5(7)
		C(5)–C(6)–C(7)	132.2(7)
		N(2)–C(6)–C(7)	105.0(6)
		C(6)–C(7)–C(8)	108.7(7)
		C(7)–C(8)–C(9)	107.6(7)
		C(8)–C(9)–N(2)	107.2(7)

These bond lengths are the same as found in the planar *Z*-configurations, indicating that the large deviation from planarity in the present case has no effect on the degree of delocalization.

The bond angles around C(5) and C(6) are of interest. They are approximately the same as found for the *Z*-antiperiplanar isomer of (II). The C(4)–C(5)–C(6) angle is large (128.4°) but not as large as found in the *syn-Z*-isomers (133°) in which there is some crowding to achieve maximum hydrogen bonding in a planar structure. The C(5)–C(6)–C(7) angle (132.2°) and C(3)–C(4)–C(5) angle (133.2°) are larger than in the corresponding *Z*-periplanar oxodipyrromethenes.

Other than the hydrogen bonded contacts already mentioned, there is only one intermolecular contact <3.5 Å between non-hydrogen atoms. This is the N(1) ··· C(5)′ distance of 3.33 Å. This is not believed to have any effect on the structure.

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