A *cis–syn* Photodimer of Thymine: Thy[1(CH$_2$–CHOH–CH$_2$)1′]Thy*

By Anna E. Kozioł

Institute of Chemistry, M. Curie-Skłodowska University, pl. M. Curie-Skłodowskiej 3, 20-031 Lublin, Poland

and Andrzej Rajchel

Institute of Chemistry, A. Mickiewicz University, ul. Grunwaldzka 6, 60-780 Poznań, Poland

Abstract. C$_{13}$H$_{16}$N$_4$O$_5$, monoclinic, $P2_1/n$, a = 6·227 (1), b = 16·222 (4), c = 13·085 (2) Å, β = 93·80 (2)°, Z = 4, D_c = 1·55 Mg m^{-3}, μ(Cu $K\alpha$) = 1·04 mm^{-1}. The final R value is 0·045 for 1446 reflexions and 199 parameters. The molecule (isomer Z) has the *cis–syn* configuration. Both pyrimidine rings adopt non-planar conformations: ring A is a distorted sofa and ring B a flattened chair. The cyclobutane ring is puckered. The seven-membered diazacycloheptane ring has a slightly twisted chair conformation.

Introduction. The investigation of base–base interactions in nucleic acid strands is strongly complicated by the hydrogen bonds or phosphodiester linkages. Knowledge of these interactions is important to elucidate the secondary or tertiary structures of nucleic acids. For elimination of some of the hydrogen bonds between bases, Browne, Eisinger & Leonard (1968) suggested the investigation of base–base interactions in the dinucleotide analogs in which the bases are connected by the polymethylene chain B–(CH$_2$)$_n$–B' (where B and B' are residues of uracil, thymine or cytosine). Some of the connexions of B–(CH$_2$)$_n$–B' type undergoing the photoreaction yield photodimers whose stereochemistry can be used as a model for natural photoproducts (Leonard, Golankiewicz, McCredie, Johnson & Paul, 1969).

The investigation of photodimers [bis(5-alkyl-uracils)] connected by the trimethylene bridge in the 1,1′-position was carried out as a continuation of studies on dinucleotide analogs (Rajchel & Golankiewicz, 1976). Thy[1(CH$_2$–CHOH–CH$_2$)1′]Thy, containing the hydroxyl group in the trimethylene bridge, is a derivative of the above-mentioned compounds (Rajchel & Golankiewicz, 1981).

Crystals were obtained by the slow cooling of an aqueous solution. A crystal of dimensions 0·15 × 0·20

× 0·40 mm, sealed in a glass capillary, was used for data collection. Cell parameters and intensities of reflexions were measured on a Syntex $P2_1$ diffractometer with monochromated Cu $K\alpha$ radiation. The θ–2θ scan mode, with variable scan rate, was applied and the integrated intensities were determined by peak-profile analysis by the method of Lehmann & Larsen (1974) (program *PRAN*; Jaskólski, 1979). The structure was solved with *MULTAN* (Germain, Main & Woolfson, 1971). All H atoms were found on a difference Fourier map. The H-atom parameters were not refined. Full-matrix least-squares refinement with 1446 reflexions [$I \geq 1\cdot96\sigma(I)$] gave R = 0·045 and R_w = 0·050. The weighting scheme was $w = F_o/F_l$ if $F_o < F_l$, $w = 1$ if F_l

Table 1. *Atomic coordinates* ($\times 10^4$) *and thermal parameters for non-hydrogen atoms*

$$B_{eq} = \tfrac{4}{3} \sum B_{ii}.$$

	x	y	z	B_{eq} (Å^2)
C(6)	658 (4)	590 (2)	2023 (2)	2·1
N(1)	−227 (4)	−86 (1)	1413 (2)	2·2
C(2)	−2080 (5)	−41 (2)	831 (2)	2·4
O(2)	−2695 (3)	−579 (1)	214 (2)	3·0
N(3)	−3375 (4)	648 (2)	954 (2)	2·7
C(4)	−3035 (5)	1243 (2)	1689 (2)	2·3
O(4)	−4508 (3)	1666 (1)	1948 (2)	3·5
C(5)	−725 (5)	1377 (2)	2066 (2)	2·1
C(9)	55 (5)	2116 (2)	1462 (2)	2·7
C(5′)	−277 (4)	1376 (2)	3277 (2)	2·1
C(9′)	1435 (5)	1996 (2)	3670 (2)	2·7
C(4′)	−2208 (5)	1453 (2)	3899 (2)	2·2
O(4′)	−2920 (4)	2112 (1)	4175 (2)	3·2
N(3′)	−3144 (4)	728 (1)	4187 (2)	2·6
O(2′)	−3419 (4)	−647 (1)	4416 (2)	3·7
C(2′)	−2407 (5)	−79 (2)	4053 (2)	2·4
N(1′)	−627 (4)	−176 (1)	3548 (2)	2·3
C(6′)	690 (5)	496 (2)	3205 (2)	2·2
C(7′)	289 (5)	−1010 (2)	3447 (2)	2·9
C(8)	−67 (5)	−1384 (2)	2387 (3)	2·8
C(7)	871 (5)	−883 (2)	1530 (2)	2·6
O(8)	−2303 (3)	−1487 (1)	2187 (2)	3·4

$\leq F_o \leq F_h$, $w = F_h/F_o$ if $F_o > F_h$, with $F_l = 4.5$ and $F_h = 25.0$. Final atomic parameters are listed in Table 1.*

Discussion. Fig. 1 illustrates the conformation and atom numbering scheme. Bond distances and angles and torsion angles are presented in Table 2.

For other photodimers of thymine {trans–anti Thy[ ]Thy (Camerman & Nyburg, 1969); cis–syn 1,3Me$_2$Thy[ ]1',3'Me$_2$Thy (Camerman & Camerman, 1970); trans–syn 1,3Me$_2$Thy[ ]1',3'Me$_2$Thy (Camerman, Weinblum & Nyburg, 1969); cis–syn Thy[1(CH$_2$)$_3$1']Thy (Leonard et al., 1969); cis–syn 3PrThy[1(CH$_2$)$_3$1']3'PrThy (Skrzypczak-Jankun, Maluszyńska, Kałuski & Golankiewicz, 1977)}, irrespective of the configurational and conformational differences, analogous bond distances of the pyrimidine ring were observed.

In comparison with Thy[1(CH$_2$)$_3$1']Thy the conformation of Thy[1(CH$_2$–CHOH–CH$_2$)1']Thy shows wide differences in spite of the chemical similarity between both molecules. In the case of Thy[1(CH$_2$)$_3$1']Thy one of the pyrimidine rings (A) is almost planar, whereas B is a twist-boat, the seven-membered ring C is very close to a chair, and cyclobutane ring D is slightly puckered with the mean deviation from the least-squares plane 0.011 Å. In the case of Thy[1(CH$_2$–CHOH–CH$_2$)1']Thy, ring A is a distorted sofa, B is a flattened chair, C is a distorted chair, and in ring D the mean deviation from the best

---

* Lists of structure factors, anisotropic thermal parameters and H-atom coordinates have been deposited with the British Library Lending Division as Supplementary Publication No. SUP 36449 (19 pp.). Copies may be obtained through The Executive Secretary, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England.
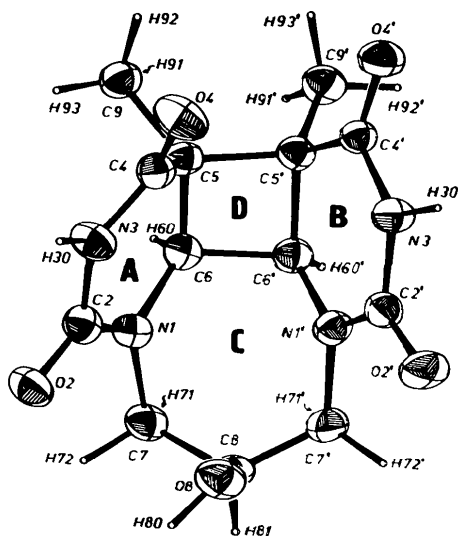

Fig. 1. The molecule of Thy[1(CH$_2$–CHOH–CH$_2$)1']Thy.

Table 2. Molecular dimensions

Bond distances (Å) (e.s.d.'s 0.004 Å)

N(1)–C(2)	1.341		N(1')–C(2')	1.337
C(2)–O(2)	1.233		C(2')–O(2')	1.229
C(2)–N(3)	1.393		C(2')–N(3')	1.402
N(3)–C(4)	1.369		N(3')–C(4')	1.375
C(4)–O(4)	1.211		C(4')–O(4')	1.221
C(4)–C(5)	1.505		C(4')–C(5')	1.501
C(5)–C(6)	1.544		C(5')–C(6')	1.554
C(5)–C(9)	1.532		C(5')–C(9')	1.529
C(6)–N(1)	1.444		C(6')–N(1')	1.453
C(5)–C(5')	1.591		C(6')–C(6)	1.552
N(1)–C(7)	1.465		N(1')–C(7')	1.478
C(7)–C(8)	1.531		C(7')–C(8)	1.517
C(8)–O(8)	1.410			

Bond angles (°) (e.s.d.'s 0.3°)

C(2)–N(1)–C(6)	123.6		C(2')–N(1')–C(6')	124.6
C(6)–N(1)–C(7)	117.0		C(6')–N(1')–C(7')	115.5
C(2)–N(1)–C(7)	119.1		C(2')–N(1')–C(7')	119.3
N(1)–C(2)–N(3)	117.5		N(1')–C(2')–N(3')	117.4
N(1)–C(2)–O(2)	123.4		N(1')–C(2')–O(2')	124.4
O(2)–C(2)–N(3)	119.1		O(2')–C(2')–N(3')	118.2
C(2)–N(3)–C(4)	125.7		C(2')–N(3')–C(4')	128.0
N(3)–C(4)–C(5)	115.6		N(3')–C(4')–C(5')	116.5
N(3)–C(4)–O(4)	120.8		N(3')–C(4')–O(4')	119.9
O(4)–C(4)–C(5)	123.5		O(4')–C(4')–C(5')	123.6
C(4)–C(5)–C(6)	113.1		C(4')–C(5')–C(6')	115.9
C(4)–C(5)–C(5')	115.3		C(4')–C(5')–C(5)	116.5
C(4)–C(5)–C(9)	105.8		C(4')–C(5')–C(9')	109.2
C(9)–C(5)–C(5')	118.3		C(9')–C(5')–C(5)	113.9
C(9)–C(5)–C(6)	115.6		C(9')–C(5')–C(6')	111.1
C(5')–C(5)–C(6)	88.5		C(5)–C(5')–C(6')	89.1
C(5)–C(6)–C(6')	90.9		C(5')–C(6')–C(6)	89.5
C(5)–C(6)–N(1)	117.1		C(5')–C(6')–N(1')	116.2
N(1)–C(6)–C(6')	117.1		N(1')–C(6')–C(6)	114.3
N(1)–C(7)–C(8)	110.3		N(1')–C(7')–C(8)	114.4
C(7)–C(8)–C(7')	114.7			
C(7)–C(8)–O(8)	110.3			
O(8)–C(8)–C(7')	107.5			

Endocyclic torsion angles (°)

Ring A

N(1)C(2)N(3)C(4)	−7.0 (4)
C(2)N(3)C(4)C(5)	28.2 (4)
N(3)C(4)C(5)C(6)	−30.1 (3)
C(4)C(5)C(6)N(1)	15.2 (3)
C(5)C(6)N(1)C(2)	5.2 (3)
C(6)N(1)C(2)N(3)	−10.7 (3)

Ring B

N(1')C(2')N(3')C(4')	−3.1 (3)
C(2')N(3')C(4')C(5')	6.4 (4)
N(3')C(4')C(5')C(6')	−11.0 (3)
C(4')C(5')C(6')N(1')	13.0 (3)
C(5')C(6')N(1')C(2')	−10.7 (3)
C(6')N(1')C(2')N(3')	5.4 (3)

Ring C

C(7)N(1)C(6)C(6')	−62.0 (3)
N(1)C(6)C(6')N(1')	−13.7 (3)
C(6)C(6')N(1')C(7')	76.2 (3)
C(8)C(7)N(1)C(6)	89.4 (3)
C(8)C(7')N(1')C(6')	−82.3 (3)
C(7)C(8)C(7')N(1')	59.1 (4)
N(1)C(7)C(8)C(7')	−64.8 (3)

Ring D

C(6)C(5)C(5')C(6')	−10.8 (3)
C(5)C(5')C(6')C(6)	10.8 (2)
C(5')C(6')C(6)C(5)	−11.1 (3)
C(6')C(6)C(5)C(5')	10.8 (2)

Table 3. Interatomic contacts

Intramolecular distances (Å)

O(8)···O(2)	2.969 (3)	C(9)···C(9')	2.965 (4)
O(8)···O(2')	3.334 (3)		

Hydrogen-bond geometry

D···A	D···A (Å)	D–H (Å)	H···A (Å)	∠D–H···A (°)
O(8)···O(4')[i]	2.896 (3)	0.96	1.97	160
N(3)···O(2)[ii]	2.800 (3)	1.02	1.82	159
N(3')···O(2')[iii]	2.909 (3)	1.02	1.90	170

Symmetry code

None	x, y, z	(ii)	$-1-x, \bar{y}, \bar{z}$
(i)	$-\frac{1}{2}-x, -\frac{1}{2}-y, \frac{1}{2}-z$	(iii)	$-1-x, \bar{y}, 1-z$

plane is 0·074 Å. The considerable distortions in the central part of the Thy[1(CH₂–CHOH–CH₂)1']Thy molecule are due to stresses caused by the interactions of the terminal substituents (Table 3). The presence of the hydroxyl group in the molecule of Thy[1(CH₂–CHOH–CH₂)1']Thy causes the packing mode to differ from that of Thy[1(CH₂)₃1']Thy. The hydroxyl O(8) is involved with the carbonyl O(2) in close intramolecular contact and with the carbonyl O(4') in the intermolecular hydrogen bond. The protonated N(3) and N(3') are hydrogen bonded to the carbonyl O(2) and O(2'), respectively. In this way thymine bases are connected in pairs about two kinds of symmetry centers.

References

BROWNE, D. T., EISINGER, J. & LEONARD, N. J. (1968). *J. Am. Chem. Soc.* **90**, 7302–7323.
CAMERMAN, N. & CAMERMAN, A. (1970). *J. Am. Chem. Soc.* **92**, 2523–2527.
CAMERMAN, N. & NYBURG, S. C. (1969). *Acta Cryst.* B25, 388–394.
CAMERMAN, N., WEINBLUM, D. & NYBURG, S. C. (1969). *J. Am. Chem. Soc.* **91**, 982–986.
COHN, W. E., LEONARD, N. J. & WANG, S. Y. (1974). *Photochem. Photobiol.* **19**, 89–94.
GERMAIN, G., MAIN, P. & WOOLFSON, M. M. (1971). *Acta Cryst.* A27, 368–376.
JASKÓLSKI, M. (1979). PhD Dissertation, A. Mickiewicz Univ. Poznań.
LEHMANN, M. S. & LARSEN, F. K. (1974). *Acta Cryst.* A30, 580–584.
LEONARD, N. J., GOLANKIEWICZ, K., MCCREDIE, R. S., JOHNSON, S. M. & PAUL, I. C. (1969). *J. Am. Chem. Soc.* **91**, 5855–5862.
RAJCHEL, A. & GOLANKIEWICZ, K. (1976). *Bull. Acad. Pol. Sci. Ser. Sci. Chim.* **25**, 439–442.
RAJCHEL, A. & GOLANKIEWICZ, K. (1981). *Biochem. Biophys. Res. Commun.* **99**, 1341–1347.
SKRZYPCZAK-JANKUN, E., MAŁUSZYŃSKA, H., KAŁUSKI, Z. & GOLANKIEWICZ, K. (1977). *Acta Cryst.* B33, 1624–1627.

Structure of 3',8-Bis[(p-chlorophenyl)thiomethoxy]-4',5,6',7-tetramethyl-chroman-2-spiro-1'-cyclohexa-3',5'-dien-2'-one: a Spirocyclic Chroman

BY P. CACIOLI, M. F. MACKAY* AND J. A. REISS

Department of Chemistry, La Trobe University, Bundoora, Victoria 3083, Australia

Abstract. $C_{32}H_{30}Cl_2O_4S_2$, triclinic, $P\bar{1}$, $a = 7.636$ (5), $b = 14.167$ (7), $c = 15.186$ (8) Å, $\alpha = 108.75$ (6), $\beta = 100.54$ (6), $\gamma = 77.41$ (6)°, $Z = 2$, $F(000) = 640$, $\mu(\text{Cu } K\alpha) = 3.39$ mm⁻¹. Final $R = 0.065$ for 2534 observed reflections. The conformation and dimensions of the pyranspirocyclohexadienone moiety are similar to those observed in the 3',8-bis(chloromethoxy) analogue [Cacioli, Mackay & Reiss (1980). *Tetrahedron Lett.* **21**, 4973–4976; Cacioli, Mackay & Reiss (1981). *Acta Cryst.* B37, 1620–1622]. The pyran ring system is in a half-chair form and the cyclohexadienone ring is envelope. In the 1,3-diene moiety, the two long and two short C–C bonds have mean values of 1·461 (8) and 1·332 (8) Å respectively.

Introduction. During the course of an investigation of the chemistry of spiroepoxycyclohexadienones, the spirocyclic chroman (I) was obtained (Cacioli *et al.*,

1980, 1981). Although spirocyclic chromans are known to undergo a number of acid-promoted rearrangement reactions (Dick, Dean, Matkin & Robinson, 1977), there are few reports of their reactions with nucleophiles. Reactions between chroman (I) and sodium methoxide, or ethoxide, gave complex mixtures of products (Cacioli & Reiss, 1981). However, on reaction with sodium *p*-chlorothiophenoxide in methanol, chroman (I) gave the nucleophilic displacement product (II). Because of ambiguity in the ¹H and ¹³C spectral data of compound (II) by comparison with that of compound (I) (Cacioli & Reiss, 1981), an X-ray structure determination of (II) was carried out.

(I): R = Cl

(II): R = S—⟨O⟩—Cl

---
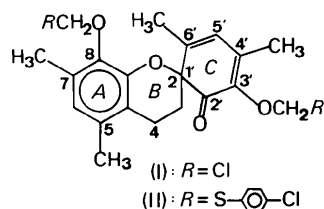
* To whom correspondence should be addressed.