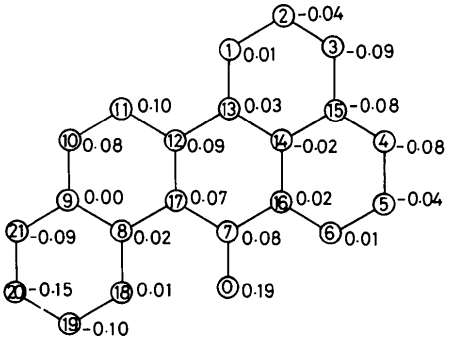

Fig. 3. Atomic displacements (Å) from the mean plane of the molecule (I). The estimated standard deviation is less than 0·02 Å.

O···H(C6); these are 2·08 (2) and 2·32 (2) Å respectively. This type of deformation is similar to that observed in dibenz[*a*,*h*]anthraquinone (Entwistle *et al.*, 1969), but the buckling of the molecular framework is much less than that reported for tetrabenzo[*a*,*cd*,*j*,*lm*]perylene (Kohno, Konno, Saito & Inokuchi, 1975).

As mentioned earlier, the molecules form dimer pairs, like pyrene (Robertson & White, 1947), perylene (Donaldson, Robertson & White, 1953) and benzo[*pqr*]perylene (White, 1948). In contrast, naphth[7,8,1,2-*defg*]anthrone (Fujisawa, Oonishi, Aoki & Iwashima, 1976) does not exhibit such a dimeric structure.

The interplanar spacing in the dimer pairs is 3·47 (1) Å in (I) and 3·52 (3) Å in (II), whereas the spacing between the pairs is 3·40 (1) Å [(I)···(I)] and 3·47 (3) Å [(II)···(II)]. The shortest C···C distance between dimer pairs (I) and (II) is 3·46 (3) Å. The interplanar spacing of 3·50 Å in naphth[7,8,1,2-*defg*]-anthrone (Fujisawa *et al.*, 1976) lies between the observed values for (I) and (II).

References

COPPENS, P. & HAMILTON, W. C. (1970). *Acta Cryst.* A**26**, 71–83.

DONALDSON, D. M., ROBERTSON, J. M. & WHITE, J. G. (1953). *Proc. R. Soc. London Ser. A*, **220**, 311–321.

ENTWISTLE, R. F., IBALL, J., MOTHERWELL, W. D. S. & THOMPSON, B. P. (1969). *Acta Cryst.* B**25**, 770–775.

FUJISAWA, S., OONISHI, I., AOKI, J. & IWASHIMA, S. (1976). *Bull. Chem. Soc. Jpn*, **49**, 3454–3456.

International Tables for X-ray Crystallography (1974). Vol. IV. Birmingham: Kynoch Press.

KOHNO, Y., KONNO, M., SAITO, Y. & INOKUCHI, H. (1975). *Acta Cryst.* B**31**, 2076–2080.

MAIN, P., WOOLFSON, M. M., LESSINGER, L., GERMAIN, G. & DECLERCQ, J. P. (1974). *MULTAN 74. A System of Computer Programs for the Automatic Solution of Crystal Structures from X-ray Diffraction Data.* Univs. of York, England, and Louvain, Belgium.

ROBERTSON, J. M. & WHITE, J. G. (1947). *J. Chem. Soc.* pp. 358–368.

SCHOLL, R. & SEER, C. (1912). *Justus Liebigs Ann. Chem.* **394**, 111–177.

STEWART, R. F., DAVIDSON, E. R. & SIMPSON, W. T. (1965). *J. Chem. Phys.* **42**, 3175–3187.

WHITE, J. G. (1948). *J. Chem. Soc.* pp. 1398–1408.

Acta Cryst. (1981). B**37**, 2197–2205

The Crystal Structure of 13-*cis*-Retinal. The Molecular Structures of its 6-*s*-*cis* and 6-*s*-*trans* Conformers

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Abstract

The crystal and molecular structure of 13-*cis*-retinal, $C_{20}H_{28}O$, has been determined by single-crystal X-ray diffraction techniques using counter methods. The structure was refined by full-matrix least-squares procedures using 2762 unique and significant (at the 2σ level) reflections to a final weighted R index of 0·062. Triclinic crystals form in the space group $P\bar{1}$ with unit-cell dimensions of a = 12·494 (6), b = 18·279 (8), c = 7·992 (5) Å, α = 100·26 (4), β = 90·26 (5), γ = 94·35 (4)°, with V = 1790 (2) Å^3, Z = 4, D_c = 1·055 Mg m^{-3}, M_r = 284·4, $F(000)$ = 624. The crystal structure discloses the presence of two conformers. In the 6-*s*-*trans* conformer, the double bond in the

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cyclohexene ring lies nearly in the plane of the polyene chain of the molecule, while in the 6-*s*-*cis* conformer, the ring is rotated 110° from this orientation. Although the greater extent of the conjugated system in the 6-*s*-*trans* conformer indicates that it has more resonance stabilization than the 6-*s*-*cis* conformer, its intramolecular contacts and distortions show that it also has a higher steric energy. For the two conformers to coexist in the crystal, these two energy differences must nearly balance.

Introduction

The early work of Wald (1968) led to the general belief that the binding site of opsin is highly stereospecific, interacting only with the structurally similar 11-*cis*- and 9-*cis*-retinal isomers. Recent experimental results, however, seem to refute his conclusions. For example, it has been shown unequivocally (Crouch, Purvin, Nakanishi & Ebrey, 1975) that 9,13-di*cis*-retinal forms a stable pigment with opsin without, as earlier thought, first undergoing geometric isomerization to 9-*cis*-retinal. Also, six new geometric isomers of retinal have since been prepared [7-*cis* (Ramamurthy & Liu, 1975; Denny & Liu, 1977), 7,9-di*cis* (Ramamurthy & Liu, 1975; Asato & Liu, 1975), 7,13-di*cis* (Ramamurthy & Liu, 1975; Kini, Asato & Liu, 1980, unpublished results), 7,9,13-tri*cis* (Ramamurthy & Liu, 1975; Asato & Liu, 1975), 7,11-di*cis* (Kini, Matsumoto & Liu, 1979), and 9,11-di*cis* (Kini, Matsumoto & Liu, 1980)] which, despite their different shapes, all form pigment analogues with cattle opsin (Kini, Matsumoto & Liu, 1979; Kini, Matsumoto & Liu, 1980; DeGrip, Liu, Ramamurthy & Asato, 1976). Thus, these results have reversed the earlier view; instead of believing that only two of the six earlier known isomers are active, we now know that only two (all-*trans* and 13-*cis*) of the twelve presently known geometric isomers are definitely inactive. (11,13-Di*cis*-retinal, not referenced here, has ambiguous activity.) Clearly, the binding site of opsin is not as stereoselective as originally thought.

The inactivity of the all-*trans* and 13-*cis* isomers led Matsumoto & Yoshizawa (1978) to postulate the existence of a longitudinal restriction to the binding site of opsin (see also Daemen, 1978). To calculate approximate molecular lengths for all retinal isomers easily, a series of assumptions about their geometries was made, namely that (1) all are planar, (2) C–C–C = 120°, C–C = 1·46, and C=C = 1·35 Å, (3) all single bonds in the polyene chain are in the *trans* configuration, and (4) the cyclohexene ring is a hexagon 1·46 Å on an edge. They concluded that the all-*trans* and 13-*cis* isomers are inactive because their chain lengths are longer than the farthest-stretchable distance between the hydrophobic pocket and the lysine residue (Matsumoto & Yoshizawa, 1975; Bownds, 1967). This plausible explanation, however, was accompanied by their erroneous prediction (a result, perhaps, of their geometrical assumptions) that both 7,9-di*cis*- and 9,11-di*cis*-retinal, the latter only recently synthesized, would also be inactive.

If retinal analogues are to be used as meaningful probes for the determination of the effective length of the binding site of opsin, accurate molecular structures of a series of them are needed. To date, however, only the structures of all-*trans*-retinal (Hamanaka, Mitsui, Ashida & Kakudo, 1972) and 11-*cis*-retinal (Gilardi, Karle & Karle, 1972) have been reported. The crystal structure of 13-*cis*-retinal is now presented; a preliminary report is available (Matsumoto, Liu, Simmons & Seff, 1980).

Experimental

13-*cis*-Retinal was prepared according to the procedure of Brown & Wald (1965). 1 g of all-*trans*-retinal (Pflatz and Bauer, Inc.) was dissolved in 500 ml of hexane and irradiated for 46 h in a Rayonette reactor with black bulbs. The progress of the photoisomerization was followed by HPLC analysis. At the end of the irradiation period, the conversion to 13-*cis*- and 9-*cis*-retinal was about 30%. Next, the mixture was filtered and evaporated to dryness and the residue dissolved in a 5% ether–hexane solvent mixture. The three retinal isomers were then separated using medium-pressure liquid chromatography (column: Lobar, size *C*, 440-37, Licroprep Si 60); the eluent was a 15% ether–hexane mixture. The three retinal isomers (13-*cis*, 9-*cis*, and all-*trans*) were identified by NMR. The 13-*cis* isomer was recrystallized from spectrograde pentane at about 273 K.

A single crystal of approximate dimensions 0·70 × 0·24 × 0·13 mm was selected for X-ray diffraction study and was mounted along its longest dimension. A Syntex four-circle computer-controlled *P*1 diffractometer with graphite-monochromatized Mo $K\alpha$ radiation ($K\alpha_1$, λ = 0·70930 Å; $K\alpha_2$, λ = 0·71359 Å) was used for the measurement of diffraction intensities. The cell constants and their standard deviations were determined by a least-squares treatment of the angular coordinates for 15 independent reflections with 2θ values up to 26·9°. Diffraction intensities were measured in a darkened room, because 13-*cis*-retinal might be light-sensitive, at 304 (1) K. The θ–2θ scan mode was used with a constant scan rate (ω) in 2θ of 2° min^{-1}. The background time to scan time ratio used was 1·0. The scan range varied from 1·63° at low 2θ to 1·89° at 2θ = 45°. The intensities of three standard reflections, measured after every 100 reflections, showed a decrease of about 14% during data collection, for which a correction using linear interpolation was applied.

Standard deviations were assigned according to the formula $\sigma(I) = [(CT + B_1 + B_2)\omega^2 + (pI)^2]^{1/2}$, where CT is the total integrated count, B_1 and B_2 are the background counts, and the intensity is $I = \omega(CT - B_1 - B_2)$. A value of 0·02 was assigned to the empirical parameter p to account for various inaccuracies. The weights (w) used in the least-squares refinement of the structural parameters were the reciprocal squares of $\sigma(F_o)$. Of the 4704 unique reflections measured, those for which $2° < 2\theta < 45°$, 2762 had intensities greater than twice their standard deviations. These intensities were corrected for Lorentz and polarization effects (Ottersen, 1976), but not for absorption (μ = 0·06 mm^{-1}). (The monochromator crystal was assumed to be half-perfect and half-mosaic in character for the polarization correction.) The atomic scattering factors for O^0, C^0 (*International Tables for X-ray Crystallography*, 1974) and H (bonded) (Stewart, Davidson & Simpson, 1965) were used.

Structure determination

A 15-atom fragment from the structure of all-*trans*-retinal (Hamanaka *et al.*, 1972) was used as input to the computer program *MULTAN* (Germain, Main & Woolfson, 1971). Wilson (1949) intensity statistics indicated centricity. An overall isotropic thermal parameter, B_i = 2·5 Å^2, was calculated from the Debye curve, and normalized structure-factor amplitudes for the 300 reflections with $|E| > 1·87$ were used to generate a three-dimensional E function. This function, phased as indicated by the solution with the largest combined figure of merit, 2·65, revealed the positions of 39 of the 42 non-H atoms. The three remaining non-H atoms were subsequently located on a Fourier difference synthesis (Hubbard, Quicksall & Jacobson, 1971). Several cycles of isotropic and then anisotropic full-matrix least-squares refinement (Gantzel, Sparks & Trueblood, 1976) of the 42 non-H atoms led to $R_1 = \sum||F_o| - |F_c||/\sum F_o = 0·13$, and $R_2 = [\sum w(|F_o| - |F_c|)^2/\sum wF_o^2]^{1/2} = 0·13$.

At this stage of the refinement, the positions of the H atoms along the polyene chains were calculated (Seff, 1971) and compared with the peaks observed in a Fourier difference synthesis. All 14 H atoms were found: 13 had electron densities ranging from 0·22 to 0·34 e Å^{-3}; one, H(15), was unusually diffuse (0·10 e Å^{-3}). Other peaks with heights greater than 2σ, σ = 0·08 e Å^{-3}, were taken from this difference function and were analyzed on the basis of plausible bonding geometries and successful refinement, *i.e.* convergence at stable positions and meaningful B values. In this manner, all the remaining H atoms were located. Four of these 56 H atoms, *viz* H(3*A*), H(24*A*), H(38*C*), and H(39*B*), refined to abnormally large B values and implausible positions. The first two atoms refined successfully, however, when their B's were fixed at values equal to those of their adjacent H atoms. The latter two atoms would not refine even with fixed B's,

Table 1. *Fractional atomic coordinates* (×10^4) *and equivalent isotropic temperature factors for the non-*H *atoms with e.s.d.'s in parentheses*

$B_{eq} = \frac{4}{3}(\beta_{11}a^2 + \cdots + \beta_{23}bc\cos\alpha)$.

	6-*s*-*cis* conformer					6-*s*-*trans* conformer			
	x	*y*	*z*	B_{eq} (Å^2)		*x*	*y*	*z*	B_{eq} (Å^2)
C(1)	7999 (4)	14187 (2)	6551 (5)	5·2 (2)	C(22)	5827 (4)	6727 (3)	8522 (6)	5·8 (2)
C(2)	8483 (5)	14835 (3)	5768 (7)	9·2 (4)	C(23)	5187 (4)	6334 (3)	9766 (7)	8·8 (3)
C(3)	8051 (6)	14877 (3)	4139 (8)	9·8 (4)	C(24)	5688 (5)	6438 (4)	11486 (8)	10·6 (4)
C(4)	8125 (4)	14154 (3)	2837 (6)	8·2 (3)	C(25)	6796 (4)	6161 (3)	11407 (6)	6·9 (2)
C(5)	7859 (3)	13450 (3)	3557 (6)	5·4 (2)	C(26)	7464 (4)	6428 (2)	10022 (5)	5·0 (2)
C(6)	7769 (3)	13474 (2)	5224 (6)	4·4 (2)	C(27)	7049 (3)	6698 (2)	8747 (5)	4·8 (2)
C(7)	7449 (3)	12798 (2)	5945 (5)	5·0 (2)	C(28)	7782 (3)	6989 (2)	7552 (6)	5·2 (2)
C(8)	6522 (3)	12402 (2)	5747 (5)	4·8 (2)	C(29)	7600 (3)	7333 (2)	6249 (5)	5·2 (2)
C(9)	6194 (4)	11754 (2)	6517 (5)	4·7 (2)	C(30)	8435 (3)	7620 (2)	5201 (5)	4·8 (2)
C(10)	5191 (4)	11409 (2)	6155 (5)	5·0 (2)	C(31)	8118 (3)	7951 (2)	3926 (5)	5·2 (2)
C(11)	4760 (4)	10761 (2)	6832 (5)	4·8 (2)	C(32)	8810 (3)	8271 (2)	2738 (6)	5·2 (2)
C(12)	3762 (4)	10431 (2)	6435 (5)	5·0 (2)	C(33)	8380 (4)	8539 (2)	1425 (6)	5·6 (2)
C(13)	3316 (4)	9772 (2)	7019 (5)	5·1 (2)	C(34)	9026 (4)	8866 (2)	165 (6)	6·0 (2)
C(14)	2345 (4)	9457 (2)	6644 (6)	6·2 (3)	C(35)	8599 (4)	9165 (3)	−1078 (6)	6·5 (2)
C(15)	1547 (5)	9695 (3)	5644 (7)	7·9 (3)	C(36)	7507 (5)	9234 (3)	−1246 (6)	7·7 (3)
C(16)	8837 (4)	14058 (3)	7907 (6)	9·0 (3)	C(37)	5433 (4)	6303 (3)	6743 (6)	7·1 (2)
C(17)	6976 (4)	14398 (3)	7465 (6)	8·2 (3)	C(38)	5510 (4)	7550 (3)	8799 (7)	7·2 (3)
C(18)	7766 (4)	12746 (3)	2266 (6)	7·6 (3)	C(39)	8648 (4)	6360 (3)	10305 (8)	6·6 (3)
C(19)	6991 (4)	11502 (2)	7679 (5)	6·6 (2)	C(40)	9589 (4)	7534 (3)	5586 (6)	7·1 (3)
C(20)	4039 (4)	9414 (2)	8127 (6)	7·2 (2)	C(41)	10233 (4)	8848 (3)	270 (6)	8·5 (3)
O(21)	680 (3)	9321 (2)	5274 (6)	13·7 (3)	O(42)	7104 (3)	9514 (2)	−2416 (5)	10·6 (2)

Table 2. *Fractional atomic coordinates* ($\times 10^3$) *for the* H *atoms with e.s.d.'s in parentheses*

	6-*s-cis* conformer				6-*s-trans* conformer		
	x	*y*	*z*		*x*	*y*	*z*
H(2*A*)	824 (6)	1543 (4)	645 (10)	H(23*A*)	436 (3)	638 (2)	973 (4)
H(2*B*)	931 (5)	1458 (4)	513 (9)	H(23*B*)	544 (3)	581 (2)	969 (4)
H(3*A*)*	714 (3)	1490 (2)	441 (5)	H(24*A*)*	589 (4)	701 (3)	1199 (6)
H(3*B*)	850 (3)	1537 (2)	360 (5)	H(24*B*)	526 (4)	612 (3)	1245 (6)
H(4*A*)	771 (3)	1418 (2)	185 (5)	H(25*A*)	713 (2)	637 (2)	1236 (4)
H(4*B*)	886 (4)	1426 (3)	251 (6)	H(25*B*)	672 (4)	555 (3)	1133 (6)
H(7)	795 (2)	1267 (2)	654 (4)	H(28)	851 (2)	689 (1)	762 (3)
H(8)	598 (3)	1257 (2)	513 (4)	H(29)	665 (4)	745 (3)	573 (7)
H(10)	460 (3)	1170 (2)	534 (5)	H(31)	722 (3)	797 (2)	373 (4)
H(11)	529 (2)	1054 (1)	753 (3)	H(32)	974 (3)	835 (2)	300 (4)
H(12)	328 (3)	1059 (2)	557 (4)	H(33)	747 (3)	846 (2)	139 (5)
H(14)	211 (3)	903 (2)	716 (5)	H(35)	903 (3)	940 (2)	−213 (5)
H(15)	169 (5)	1010 (3)	505 (8)	H(36)	711 (4)	905 (3)	−35 (6)
H(16*A*)	919 (5)	1454 (4)	880 (8)	H(37*A*)	462 (3)	632 (2)	675 (4)
H(16*B*)	955 (4)	1395 (2)	717 (6)	H(37*B*)	542 (6)	567 (4)	633 (9)
H(16*C*)	829 (6)	1380 (4)	821 (8)	H(37*C*)	569 (3)	650 (2)	595 (4)
H(17*A*)	671 (4)	1391 (2)	830 (6)	H(38*A*)	579 (4)	795 (3)	797 (6)
H(17*B*)	713 (3)	1490 (2)	838 (5)	H(38*B*)	463 (4)	755 (3)	839 (6)
H(17*C*)	655 (4)	1433 (3)	724 (7)	H(38*C*)†	630	786	1016
H(18*A*)	722 (3)	1269 (2)	159 (5)	H(39*A*)	920 (5)	686 (3)	1053 (7)
H(18*B*)	865 (5)	1278 (3)	167 (7)	H(39*B*)†	878	586	1078
H(18*C*)	781 (3)	1225 (2)	267 (5)	H(39*C*)	912 (5)	629 (3)	939 (7)
H(19*A*)	676 (3)	1103 (2)	792 (4)	H(40*A*)	999 (4)	770 (3)	465 (6)
H(19*B*)	716 (3)	1189 (2)	855 (4)	H(40*B*)	980 (5)	772 (4)	675 (8)
H(19*C*)	749 (6)	1130 (4)	691 (9)	H(40*C*)	967 (4)	698 (3)	536 (6)
H(20*A*)	374 (4)	894 (3)	844 (6)	H(41*A*)	1076 (3)	917 (2)	−50 (5)
H(20*B*)	421 (3)	972 (2)	919 (4)	H(41*B*)	1053 (3)	901 (2)	144 (4)
H(20*C*)	498 (5)	937 (3)	777 (7)	H(41*C*)	1051 (5)	823 (3)	62 (7)

* Atoms H(3*A*) and H(24*A*) were refined with fixed *B*'s.

† Atoms H(38*C*) and H(39*B*) would not refine with fixed *B*'s: their atomic coordinates were taken from a final Fourier difference function and no corresponding e.s.d.'s are reported.

so their positions were taken directly from a Fourier difference synthesis and they were assigned *B*'s equal to the means of the other H atoms in their respective methyl groups.

Finally, several cycles of full-matrix least-squares refinement with anisotropic thermal parameters for the 42 non-H atoms and isotropic thermal parameters for the 56 H atoms led to the final error indices $R_1 = 0{\cdot}071$ and $R_2 = 0{\cdot}062$. The 'goodness-of-fit', $[\sum w(F_o - |F_c|)^2/(m-s)]^{1/2}$, is 2·45. The number of observations used in least-squares refinement (2762) is m, and s (593) is the total number of parameters. In the final cycle of least-squares refinement, the largest shift in a non-H positional or thermal parameter was 71% of its corresponding e.s.d. and for an H parameter, 80%.

The final Fourier difference function, whose e.s.d. is 0·04 e Å^{-3}, was featureless. The largest residual peaks were ≤0·15 e Å^{-3} in height and most were located near atoms with high thermal motion. Several of these weak peaks were located in the vicinity of the two C atoms opposite to the double bond in the cyclohexene ring of the 6-*s-cis* conformer, and near the two *gem*-methyl C atoms of the same ring. This is indicative of a conformational disorder present in this ring (see *Results and discussion*). The final positional coordinates are given in Tables 1 and 2; bond lengths and angles are given in Table 3.*

Results and discussion

The conformers of 13-*cis*-retinal are shown in Fig. 1. It is seen that 13-*cis*-retinal molecules exist in two conformations: the 6-*s-cis* conformer, molecule C(1)–O(21), with a C(5)–C(6)–C(7)–C(8) torsion angle (henceforth denoted φ_{6-7}) of −65·4 (6)°, and the nearly planar 6-*s-trans* conformer, molecule C(22)–O(42), with a corresponding torsion angle of −174·9 (4)°. Stam (1972) had found the 6-*s-cis* and 6-*s-trans* conformers of vitamin-A acid in separate crystal structures; in this work, both retinal conformers are found in the same crystal.

* Lists of structure factors, anisotropic thermal parameters, H-atom parameters and Fig. 3 have been deposited with the British Library Lending Division as Supplementary Publication No. SUP 36036 (21 pp.). Copies may be obtained through The Executive Secretary, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England.

Table 3. *Bond lengths* (Å) *and angles* (°) *with e.s.d.'s in parentheses*

6-*s-cis* conformer		6-*s-trans* conformer	
C(1)–C(2)	1·523 (7)	C(22)–C(23)	1·523 (7)
C(1)–C(6)	1·534 (6)	C(22)–C(27)	1·542 (6)
C(1)–C(16)	1·563 (7)	C(22)–C(37)	1·551 (6)
C(1)–C(17)	1·517 (7)	C(22)–C(38)	1·564 (7)
C(2)–C(3)	1·424 (8)	C(23)–C(24)	1·483 (8)
C(3)–C(4)	1·540 (8)	C(24)–C(25)	1·507 (8)
C(4)–C(5)	1·515 (7)	C(25)–C(26)	1·516 (6)
C(5)–C(6)	1·331 (6)	C(26)–C(27)	1·328 (6)
C(5)–C(18)	1·496 (7)	C(26)–C(39)	1·513 (7)
C(6)–C(7)	1·483 (6)	C(27)–C(28)	1·465 (6)
C(7)–C(8)	1·311 (6)	C(28)–C(29)	1·336 (6)
C(8)–C(9)	1·463 (6)	C(29)–C(30)	1·465 (6)
C(9)–C(10)	1·364 (6)	C(30)–C(31)	1·346 (6)
C(9)–C(19)	1·510 (6)	C(30)–C(40)	1·499 (6)
C(10)–C(11)	1·456 (6)	C(31)–C(32)	1·456 (6)
C(11)–C(12)	1·354 (6)	C(32)–C(33)	1·359 (6)
C(12)–C(13)	1·443 (6)	C(33)–C(34)	1·474 (6)
C(13)–C(14)	1·313 (7)	C(34)–C(35)	1·343 (7)
C(13)–C(20)	1·522 (6)	C(34)–C(41)	1·513 (7)
C(14)–C(15)	1·416 (7)	C(35)–C(36)	1·388 (9)
C(15)–O(21)	1·241 (7)	C(36)–O(42)	1·263 (7)
C(2)–C(1)–C(6)	112·3 (4)	C(23)–C(22)–C(27)	112·5 (4)
C(2)–C(1)–C(16)	106·1 (4)	C(23)–C(22)–C(37)	104·4 (4)
C(2)–C(1)–C(17)	110·0 (4)	C(23)–C(22)–C(38)	107·4 (4)
C(6)–C(1)–C(16)	110·3 (4)	C(27)–C(22)–C(37)	111·0 (4)
C(6)–C(1)–C(17)	109·9 (4)	C(27)–C(22)–C(38)	111·1 (4)
C(16)–C(1)–C(17)	108·0 (4)	C(37)–C(22)–C(38)	110·3 (4)
C(1)–C(2)–C(3)	114·8 (5)	C(22)–C(23)–C(24)	114·0 (5)
C(2)–C(3)–C(4)	112·9 (5)	C(23)–C(24)–C(25)	111·1 (6)
C(3)–C(4)–C(5)	113·8 (5)	C(24)–C(25)–C(26)	112·5 (4)
C(4)–C(5)–C(6)	121·1 (4)	C(25)–C(26)–C(27)	123·5 (4)
C(4)–C(5)–C(18)	114·8 (4)	C(25)–C(26)–C(39)	111·5 (4)
C(6)–C(5)–C(18)	124·1 (4)	C(27)–C(26)–C(39)	125·0 (4)
C(1)–C(6)–C(5)	123·6 (4)	C(22)–C(27)–C(26)	121·7 (4)
C(1)–C(6)–C(7)	114·6 (3)	C(22)–C(27)–C(28)	119·7 (4)
C(5)–C(6)–C(7)	121·8 (4)	C(26)–C(27)–C(28)	118·5 (4)
C(6)–C(7)–C(8)	127·2 (4)	C(27)–C(28)–C(29)	131·4 (4)
C(7)–C(8)–C(9)	127·1 (4)	C(28)–C(29)–C(30)	124·9 (4)
C(8)–C(9)–C(10)	118·8 (4)	C(29)–C(30)–C(31)	117·6 (4)
C(8)–C(9)–C(19)	117·8 (4)	C(29)–C(30)–C(40)	119·2 (4)
C(10)–C(9)–C(19)	123·4 (4)	C(31)–C(30)–C(40)	123·2 (4)
C(9)–C(10)–C(11)	124·6 (4)	C(30)–C(31)–C(32)	126·5 (4)
C(10)–C(11)–C(12)	122·9 (4)	C(31)–C(32)–C(33)	120·5 (4)
C(11)–C(12)–C(13)	124·9 (4)	C(32)–C(33)–C(34)	123·7 (4)
C(12)–C(13)–C(14)	124·8 (4)	C(33)–C(34)–C(35)	123·5 (4)
C(12)–C(13)–C(20)	117·1 (4)	C(33)–C(34)–C(41)	117·7 (4)
C(14)–C(13)–C(20)	118·2 (4)	C(35)–C(34)–C(41)	118·7 (4)
C(13)–C(14)–C(15)	127·5 (4)	C(34)–C(35)–C(36)	123·2 (5)
C(14)–C(15)–O(21)	121·7 (5)	C(35)–C(36)–O(42)	123·3 (5)

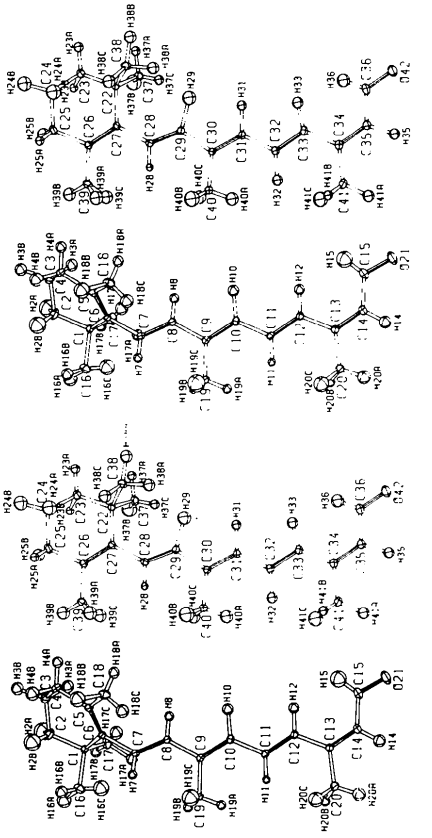

Fig. 1. Stereoview (Johnson, 1971) of the 6-*s-cis* and 6-*s-trans* conformers of 13-*cis*-retinal which coexist in the crystal structure (5% probability ellipsoids are shown). The two conformers are shown with the orientations of the C(11)–C(12) and the C(32)–C(33) bonds the same to facilitate comparison. The C(5)–C(6)–C(7)–C(8) and C(26)–C(27)–C(28)–C(29) torsion angles are −65·4 (6) and −174·9 (4)° respectively.

Either the twisted 6-*s-cis* ($40° < |\varphi_{6-7}| < 65°$) or the nearly planar 6-*s-trans* ($165° < |\varphi_{6-7}| < 175°$) conformers are found in vitamin-A-related compounds and carotenoids (Table 4). The preponderance of twisted 6-*s-cis* structures suggests that this may be the preferred conformation. The torsional potential calculated for the rotation of the cyclohexene ring about the C(6)–C(7) bond in retinals (Honig, Warshel & Karplus, 1975) shows a broad minimum centered at about 60°, and a sharper minimum centered at about 180° at slightly higher (*ca* 8·4–12·6 kJ mol^{-1}) energy. Both the magnitudes and the spread of the crystallographically observed φ_{6-7} torsion angles for the 6-*s-cis* conformers (41 to 65°) and for the 6-*s-trans* conformers (166 to 175°) are consistent with the theoretical results, although crystal-packing forces and the structure of the polyene chains are also factors which influence the φ_{6-7} values.

According to the data in Table 4, the φ_{6-7} torsion angles for the two conformers of 13-*cis*-retinal are, within their classes, the largest yet observed crystallographically for a vitamin-A-related compound or carotenoid. This may, however, just be the result of crystal-packing forces.

The 6-*s-cis* conformer, because of its twisted ring-chain orientation, would be expected to have a somewhat longer C(6)–C(7) bond than the 6-*s-trans* conformer; this expectation is fulfilled: the C(6)–C(7) bond distances are 1·483 (6) and 1·465 (6) Å respectively.

The C(6)–C(7)–C(8) bond angle for the 6-*s-cis* conformer, 127·2 (4)°, is considerably smaller than the corresponding angle for the 6-*s-trans* conformer, 131·4 (4)°. This difference results from short intramolecular contacts in the 6-*s-trans* conformer: H(29)···H(37*C*) = 2·07 (6) Å and H(29)···H(38*A*) = 2·19 (7) Å; see Figs. 1 and 2. The corresponding angles for the 6-*s-cis* and 6-*s-trans* conformers in Table 4, 123·2 to 128·2° and 130·3 to 131·9° respectively, indicate that this effect is quite general for this class of compounds.

Table 4. C(5)–C(6)–C(7)–C(8) *torsion angles* (°) *for vitamin-A-related compounds and carotenoids with e.s.d.'s in parentheses*

Each compound in this table crystallizes in a centrosymmetric space group. Accordingly, each structure contains enantiomers with positive and negative torsion angles. Only positive angles are given.

Compound	C(5)–C(6)–C(7)–C(8)	Reference
(*A*) 6-*s-cis* conformers		
Vitamin-A acid (6-*s-cis* conformer)	41·2 (5)	1
11-*cis*-Retinal	41·4 (7)	2
15,15′-Dehydrocanthaxanthin	43 (7)	3
2-*cis*-4-Hydroxyretonic acid γ-lactone	47·4 (7)	4
2,6-Di*cis*-4-hydroxyretonic acid γ-lactone	48·3 (6)	5
Canthaxanthin	52 (18)	6
Methyl 7,9-di*cis*-retinoate	53 (3)	7
(*E*)-4-Methyl-5-[5-(2,6,6-trimethyl-cyclohexen-1-yl)-3-methyl-2(*E*),4(*E*)-pentadienylidene]-2(5*H*)-furanone	53*	8
Vitamin-A acetate	57·9 (4)	9
All-*trans*-retinal	58·3 (6)	10
9-Ethyl analogue of vitamin-A acid	63·8 (6)	11
13-*cis*-Retinal (6-*s-cis* conformer)	65·4 (6)	12
(*B*) 6-*s-trans* conformers		
Vitamin-A acid (6-*s-trans* conformer)	165·8 (3)	1
1,14-Bis(2′,6′,6′-trimethylcyclohex-1′-enyl)-3,12-dimethyltetradeca-1,3,5,7,9,11,13-heptaene-6,9-dinitrile	166·4 (5)	13
3-(1,1,5-Trimethyl-5-cyclohexen-6-yl)-propenoic acid	168·5 (3)	14
9,10-*trans*-β-Ionylidene-γ-crotonic acid	169·0 (7)	15
13-*cis*-Retinal (6-*s-trans* conformer)	174·9 (4)	12

References: (1) Stam (1972); (2) Gilardi *et al.*, (1972); (3) Bart & MacGillavry (1968*a*); (4) Thackeray & Gafner (1974); (5) Thackeray & Gafner (1975); (6) Bart & MacGillavry (1968*b*); (7) Liu, Simmons, Kini, Asato & Seff, 1980, unpublished results; (8) Blount, Han, Pawson, Pitcher & Williams (1976); (9) Oberhänsli, Wagner & Isler (1974); (10) Hamanaka, Mitsui, Ashida & Kakudo (1972); (11) Schenk, Kops, van der Putten & Bode (1978); (12) this work; (13) Braun, Hornstra & Leenhouts (1971); (14) Schenk (1972); (15) Koch (1972).

* The e.s.d. cannot be calculated from the information provided.

Although the polyene chains of the two 13-*cis*-retinal conformers are similar, there are some differences. For steric reasons, the C–C–C bond angles along the chains opposite the methyl groups are compressed in both conformers, a feature commonly observed in related structures. However, they are more compressed in the 6-*s-trans* conformer: C(29)–C(30)–C(31) = 117·6 (4) *vs* C(8)–C(9)–C(10) = 118·8 (4)°; C(31)–C(32)–C(33) = 120·5 (4) *vs* C(10)–C(11)–C(12) = 122·9 (4)°; C(33)–C(34)–C(35) = 123·5 (4) *vs* C(12)–C(13)–C(14) = 124·8 (4)°; and C(34)–C(35)–C(36) = 123·2 (5) *vs* C(13)–C(14)–C(15) = 127·5 (4)°. The greater compression in the 6-*s-trans* conformer, a result of the short H(29)···H(37*C*), H(38*A*) contacts, is also evident in the shorter H···H intramolecular distances along this side of the chain for the 6-*s-trans* conformer; see Fig. 2. {That the polyene chain is generally more warped in the 6-*s-trans* conformer than in the 6-*s-cis* conformer is apparent by comparing the deviations of some of the torsion angles of the former from 180 or 0° [φ_{31-32} = 174·9 (4), φ_{33-34} = −176·5 (5), and φ_{34-35} = 3·9 (8)°], with the smaller deviations of the corresponding torsion angles of the latter [φ_{10-11} = −179·6 (4), φ_{12-13} = 179·4 (4), and φ_{13-14} = −1·2 (8)°]; see Table 5 and planes 2 and 4 in Table 6.}

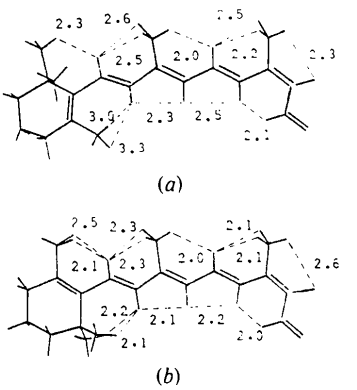

Fig. 2. Intramolecular H···H distances (Å). (*a*) 6-*s-cis* conformer. (*b*) 6-*s-trans* conformer. The 2·3 Å contact given between H(7) and H(16*C*) is likely to be inaccurately short; note in Fig. 1 that H(16*C*) appears to be misplaced with respect to the remainder of its methyl group.

Table 5. *Selected torsion angles* (°) *with e.s.d.'s in parentheses*

The signs of the torsion angles follow the conventions adopted by the IUPAC–IUB Commission on Biochemical Nomenclature (1970). The signs of the torsion angles are appropriate for the enantiomers shown in Fig. 1.

6-*s-cis* conformer		6-*s-trans* conformer	
C(1) C(2) C(3) C(4)	55·3 (7)	C(22)–C(23) C(24) C(25)	58·5 (6)
C(2) C(3) C(4) C(5)	41·3 (7)	C(23) C(24) C(25) C(26)	46·5 (6)
C(3) C(4) C(5) C(6)	11·5 (7)	C(24) C(25) C(26) C(27)	16·9 (7)
C(4) C(5) C(6) C(1)	4·5 (7)	C(25) C(26) C(27) C(22)	3·1 (6)
C(5) C(6) C(1) C(2)	7·7 (6)	C(26) C(27) C(22) C(23)	6·9 (6)
C(6) C(1) C(2) C(3)	38·3 (6)	C(27) C(22) C(23) C(24)	37·7 (6)
C(1) C(6) C(7) C(8)	115·6 (5)	C(22) C(27) C(28) C(29)	3·9 (7)
C(5) C(6) C(7) C(8)	65·4 (6)	C(26) C(27) C(28) C(29)	174·9 (4)
C(6) C(7) C(8) C(9)	177·2 (4)	C(27) C(28) C(29) C(30)	177·4 (4)
C(7) C(8) C(9) C(10)	179·8 (4)	C(28) C(29) C(30) C(31)	179·8 (4)
C(8) C(9) C(10) C(11)	179·9 (4)	C(29) C(30) C(31) C(32)	179·8 (4)
C(9) C(10) C(11) C(12)	179·6 (4)	C(30) C(31) C(32) C(33)	174·9 (4)
C(10) C(11) C(12) C(13)	177·4 (4)	C(31) C(32) C(33) C(34)	179·6 (4)
C(11) C(12) C(13) C(14)	179·4 (4)	C(32) C(33) C(34) C(35)	176·5 (5)
C(12) C(13) C(14) C(15)	1·2 (8)	C(33) C(34) C(35) C(36)	3·9 (8)
C(13) C(14) C(15) O(21)	174·8 (5)	C(34) C(35) C(36) O(42)	180·0 (5)
C(7) C(6) C(1) C(16)	53·2 (5)	C(28) C(27) C(22) C(37)	57·9 (5)
C(7) C(6) C(1) C(17)	65·8 (4)	C(28) C(27) C(22) C(38)	65·3 (5)
C(7) C(6) C(5) C(18)	6·7 (7)	C(28) C(27) C(26) C(39)	3·1 (7)
C(7) C(8) C(9) C(19)	0·3 (6)	C(28) C(29) C(30) C(40)	0·2 (6)
C(11) C(10) C(9) C(19)	0·0 (6)	C(32) C(31) C(30) C(40)	0·1 (7)
C(11) C(12) C(13) C(20)	1·7 (6)	C(32) C(33) C(34) C(41)	4·8 (7)
C(15) C(14) C(13) C(20)	179·9 (5)	C(36) C(35) C(34) C(41)	177·4 (5)

Table 6. *Least-squares planes and deviations* (Å) *of individual atoms from them*

The equation of a plane is of the form $Ax' + By' + Cz' = D$ and refers to an orthogonal system of axes with **b'** ∥ **b**, **c'** ∥ **c***, and **a'** in the **ab** plane. D is the origin-to-plane distance in Å. Atoms denoted by an asterisk were given zero weight in calculating the plane; all other atoms were equally weighted. A negative deviation from a plane indicates that the atom with the coordinates given in Table 1 or 2 lies between the plane and the origin. E.s.d.'s of deviations are: C or O, 0·005 Å; H, 0·04 Å.

Plane (1): cyclohexene ring of the 6-*s*-*cis* conformer

$$0{\cdot}9688x' - 0{\cdot}2366y' + 0{\cdot}0742z' = 4{\cdot}140$$

C(1)	0·068	C(18)	0·070
C(4)	−0·053	C(2)*	0·321
C(5)	−0·019	C(3)*	−0·355
C(6)	−0·010	C(16)*	1·259
C(7)	−0·055	C(17)*	−1·210

Plane (2): polyene chain of the 6-*s*-*cis* conformer

$$-0{\cdot}3686x' + 0{\cdot}4808y' + 0{\cdot}7956z' = 10{\cdot}862$$

C(6)	−0·004	C(19)	0·036
C(7)	−0·031	C(20)	−0·057
C(8)	−0·023	O(21)	−0·048
C(9)	0·006	H(7)*	−0·06
C(10)	0·006	H(8)*	0·05
C(11)	0·035	H(10)*	0·10
C(12)	0·025	H(11)*	−0·03
C(13)	0·000	H(12)*	−0·08
C(14)	0·002	H(14)*	0·04
C(15)	0·052	H(15)*	0·00

Plane (3): cyclohexene ring of the 6-*s*-*trans* conformer

$$0{\cdot}0565x' + 0{\cdot}8263y' + 0{\cdot}5604z' = 12{\cdot}888$$

C(22)	−0·029	C(39)	−0·031
C(25)	0·039	C(23)*	−0·216
C(26)	−0·010	C(24)*	0·492
C(27)	−0·009	C(37)*	−1·238
C(28)	0·039	C(38)*	1·307

Plane (4): polyene chain of the 6-*s*-*trans* conformer

$$0{\cdot}0506x' + 0{\cdot}7928y' + 0{\cdot}6074z' = 12{\cdot}818$$

C(27)	−0·012	C(23)*	−0·147
C(28)	−0·035	C(24)*	0·624
C(29)	−0·009	C(25)*	0·181
C(30)	0·016	C(26)*	0·055
C(31)	0·036	C(37)*	−1·294
C(32)	0·058	C(38)*	1·260
C(33)	−0·026	C(39)*	0·045
C(34)	−0·018	H(28)*	−0·16
C(35)	−0·033	H(29)*	−0·01
C(36)	0·020	H(31)*	0·01
C(40)	0·018	H(32)*	0·25
C(41)	−0·020	H(33)*	−0·14
O(42)	0·005	H(35)*	−0·08
C(22)*	−0·038	H(36)*	0·09

Dihedral angles: planes (1) and (2), 65·7°; planes (3) and (4), 3·3°.

The side-chain methyl groups have one H atom nearly eclipsing a double bond, thus showing the usual behavior of a methyl group attached to a double bond (Herschbach & Krisher, 1958); this causes the short contacts H(11)···H(19*A*) = 1·98 (5), H(32)···H(40*A*) = 1·96 (6), H(14)···H(20*A*) = 2·31 (6), and H(35)···H(41*A*) = 2·62 (6) Å.

The following equation has been proposed to be a measure of the in-plane bending in a polyene chain (Schenk, 1971): $\Delta = a - b + c - d + e - f$, where the angles a to f are the chain angles associated with atoms C(8) to C(13). The Δ values for the 6-*s*-*cis* and 6-*s*-*trans* conformers of 13-*cis*-retinal are 10·1 and 13·5° respectively, indicative of the greater strain in the latter conformer. Nevertheless, both values are considerably less than that calculated for vitamin-A acetate (26·4°), all-*trans*-retinal (19·5°), and the 6-*s*-*cis* and 6-*s*-*trans* conformers of vitamin-A acid (16·4 and 18·8° respectively), but are larger than that observed for didesmethyl-vitamin-A acid (3·2°), where the C(19) and C(20) methyl groups are missing (Oberhänsli, Wagner & Isler, 1974).

The bond distances in both chains show the alternation of shorter and longer bonds, and a systematic decrease in the alternative character of the single and double bonds towards the center of the chains, a characteristic commonly observed in such conjugated systems. The C(14)–C(15) and C(35)–C(36) bonds, however, appear to be unusually short, 1·416 (7) and 1·388 (9) Å respectively. Finally, one notes that both conformers have, for steric reasons, the C–O aldehyde bond *trans* with respect to the C(14)–C(15) and C(35)–C(36) bonds.

Another difference between the structures of the two conformers of 13-*cis*-retinal is the length of the C(2)–C(3) bond in the 6-*s*-*cis* conformer, 1·424 (8) Å, compared to the corresponding bond in the 6-*s*-*trans* conformer, C(23)–C(24) = 1·483 (8) Å. An examination of the molecular geometry reported for the compounds listed in Table 4 shows that the C(2)–C(3) bond is usually shorter and varies more in the 6-*s*-*cis* conformers (1·24 to 1·51 Å) than in the 6-*s*-*trans* conformers (1·46 to 1·50 Å).

The short C(2)–C(3) bonds found in some 6-*s*-*cis* conformers have been attributed, at least in part, to a conformational disorder of the cyclohexene ring. The conformation of the rings is half chair, with C(2) and C(3) on opposite sides of the plane through C(1), C(6), C(5), and C(4). Apparently, a fraction of the molecules have C(2) and C(3) switched to the other side of the plane, giving rise to alternative positions of the *gem*-methyl groups, C(16) and C(17). Evidence of this disorder in the 6-*s*-*cis* conformer of 13-*cis*-retinal, apart from the short C(2)–C(3) bond, is the weak residual peaks (*ca* 0·13 e Å^{-3} in height) on the final Fourier difference function in the vicinity of C(2), C(3), C(16), and C(17), and the absence of such peaks in the vicinity of the corresponding atoms for the 6-*s*-*trans* conformer. [Interestingly, the largest r.m.s. components of the thermal ellipsoids for C(2), C(3), C(16), and C(17), 0·41, 0·45, 0·38, and 0·40 Å respectively, are comparable to those of C(23), C(24), C(37), and

Table 7. *Intermolecular distances* (Å) *with e.s.d.'s in parentheses*

C–C < 3·5, C–O < 3·3, C–H < 3·0, O–O < 3·1, O–H < 2·8, H–H < 2·55 Å.

C(12)···H(33^{i})	2·96 (4)	H(10)···H(29^{i})	2·53 (6)
C(14)···H(19C^{i})	2·94 (7)	H(10)···H(31^{i})	2·48 (6)
C(15)···H(19C^{i})	2·82 (7)	H(14)···H(18C^{i})	2·38 (6)
C(17)···H(24B^{ii})	2·89 (5)	H(14)···H(41A^{vii})	2·52 (6)
C(23)···H(17A^{ii})	2·89 (4)	H(17A)···H(23A^{ii})	2·18 (6)
C(26)···H(17B^{iii})	2·88 (4)	H(17A)···H(24B^{ii})	2·52 (6)
C(28)···H(2A^{iii})	2·93 (8)	H(17B)···H(25B^{viii})	2·52 (6)
C(32)···H(39A^{iv})	2·93 (6)	H(17C)···H(24B^{ii})	2·38 (7)
O(21)···H(32^{v})	2·52 (4)	H(18A)···H(38B^{i})	2·32 (6)
O(42)···H(12^{vi})	2·54 (4)	H(20B)···H(20B^{ii})	2·41 (6)
O(42)···H(15^{vi})	2·76 (6)	H(24A)···H(31^{ix})	2·54 (6)
O(42)···H(20C^{iv})	2·65 (6)	H(33)···H(38C^{iv})	2·17*

Symmetry code: none x,y,z; (i) $1-x, 2-y, 1-z$; (ii) $1-x, 2-y, 2-z$; (iii) $x, -1+y, z$; (iv) $x, y, -1+z$; (v) $-1+x, y, z$; (vi) $1-x, 2-y, -z$; (vii) $-1+x, y, 1+z$; (viii) $x, 1+y, z$; (ix) $x, y, 1+z$.

* The final atomic coordinates for H(38C) were estimated from a Fourier difference function; hence no e.s.d. is reported for this value.

C(38), 0·45, 0·49, 0·36, and 0·34 Å respectively.| It may be that there is less conformational disorder in the rings for the 6-*s*-*trans* conformers because of the orientation of H(29) with respect to the *gem*-methyl groups, C(37) and C(38); H(29) seems to 'lock-in' the two methyls and makes the ring stiffer.

Aside from the difference in C(2)–C(3) bond lengths, the geometries of the cyclohexene rings for both conformers are similar; the ring torsion angles (Table 5) are within *ca* 5° of each other, and are comparable to those reported for similar structures (Stam, 1972; Oberhänsli *et al.*, 1974).

The packing of the two conformers of 13-*cis*-retinal is shown in Fig. 3;* intermolecular contacts are listed in Table 7. There are no C···C, C···O, or O···O contacts less than 3·5, 3·3, and 3·1 Å respectively. Packing seems to be primarily influenced by van der Waals interactions between H atoms. There are a few H···H contacts in the 2·1–2·2 Å range, and many at slightly longer distances (2·2–2·5 Å).

Recent molecular-mechanics strain-energy-minimization calculations for a series of isolated retinal isomers (Sharpless, 1981) yield φ_{6-7} torsion angles which are quite different from those observed. For example, the optimum φ_{6-7} torsion angle calculated for 13-*cis*-retinal is 6·2 *vs* 65·4 and 174·9° observed; for all-*trans*-retinal, 9·1 *vs* 58·3° observed; for 11-*cis*-retinal, 13 *vs* 41·4° observed; and for 7,9-di*cis*-retinal, 32·6 *vs* 53° observed. Crystal-packing forces may contribute to these differences.

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* See deposition footnote.

References

ASATO, A. E. & LIU, R. S. H. (1975). *J. Am. Chem. Soc.* **97**, 4128–4130.

BART, J. C. J. & MACGILLAVRY, C. H. (1968*a*). *Acta Cryst.* B**24**, 1569–1587.

BART, J. C. J. & MACGILLAVRY, C. H. (1968*b*). *Acta Cryst.* B**24**, 1587–1606.

BLOUNT, J. F., HAN, R.-J. L., PAWSON, B. A., PITCHER, R. G. & WILLIAMS, T. H. (1976). *J. Org. Chem.* **41**, 4108–4110.

BOWNDS, D. (1967). *Nature (London)*, **216**, 1178–1181.

BRAUN, P. B., HORNSTRA, J. & LEENHOUTS, J. I. (1971). *Acta Cryst.* B**27**, 90–95.

BROWN, P. K. & WALD, G. (1965). *J. Biol. Chem.* **222**, 865–877.

CROUCH, R., PURVIN, V., NAKANISHI, K. & EBREY, T. (1975). *Proc. Natl Acad. Sci. USA*, **72**, 1538–1542.

DAEMEN, F. J. M. (1978). *Nature (London)*, **276**, 847–848.

DEGRIP, W., LIU, R. S. H., RAMAMURTHY, V. & ASATO, A. E. (1976). *Nature (London)*, **262**, 416–418.

DENNY, M. & LIU, R. S. H. (1977). *J. Am. Chem. Soc.* **99**, 4865–4867.

GANTZEL, P. K., SPARKS, R. A. & TRUEBLOOD, K. (1976). *UCLALS4*. American Crystallographic Association Program Library (old) No. 317, modified by K. SEFF & T. OTTERSEN.

GERMAIN, G., MAIN, P. & WOOLFSON, M. M. (1971). *Acta Cryst.* A**27**, 368–376.

GILARDI, R. D., KARLE, I. L. & KARLE, J. (1972). *Acta Cryst.* B**28**, 2605–2612.

HAMANAKA, T., MITSUI, T., ASHIDA, T. & KAKUDO, M. (1972). *Acta Cryst.* B**28**, 214–222.

HERSCHBACH, D. R. & KRISHER, L. C. (1958). *J. Chem. Phys.* **28**, 728–729.

HONIG, B., WARSHEL, A. & KARPLUS, M. (1975). *Acc. Chem. Res.* **8**, 92–100.

HUBBARD, C. R., QUICKSALL, C. O. & JACOBSON, R. A. (1971). *ALFF*. (Ames Laboratory Fast Fourier.) Iowa State Univ., USA.

International Tables for X-ray Crystallography (1974). Vol. IV, pp. 72–98. Birmingham: Kynoch Press.

IUPAC–IUB COMMISSION ON BIOCHEMICAL NOMENCLATURE (1970). *J. Mol. Biol.* **52**, 1–17.

JOHNSON, C. K. (1971). *ORTEP* II. Report ORNL-TM-5138. Oak Ridge National Laboratory, Tennessee.

KINI, A., MATSUMOTO, H. & LIU, R. S. H. (1979). *J. Am. Chem. Soc.* **101**, 5078–5079.

KINI, A., MATSUMOTO, H. & LIU, R. S. H. (1980). *Bioorg. Chem.* **9**, 406–410.

KOCH, B. (1972). *Acta Cryst.* B**28**, 1151–1159.

MATSUMOTO, H., LIU, R. S. H., SIMMONS, C. J. & SEFF, K. (1980). *J. Am. Chem. Soc.* **102**, 4259–4262.

MATSUMOTO, H. & YOSHIZAWA, T. (1975). *Nature (London)*, **258**, 523–526.

MATSUMOTO, H. & YOSHIZAWA, T. (1978). *Vision Res.* **18**, 607–609.

OBERHÄNSLI, W. E., WAGNER, H. P. & ISLER, O. (1974). *Acta Cryst.* B**30**, 161–166.

OTTERSEN, T. (1976). *LP* 76. Univ. of Hawaii.

RAMAMURTHY, V. & LIU, R. S. H. (1975). *Tetrahedron*, **31**, 201–206.

SCHENK, H. (1971). *Acta Cryst.* B**27**, 667–672.

SCHENK, H. (1972). *Cryst. Struct. Commun.* **1**, 143–146.
SCHENK, H., KOPS, R. T., VAN DER PUTTEN, N. & BODE, J. (1978). *Acta Cryst.* B**34**, 505–507.
SEFF, K. (1971). *HFIND*. Univ. of Hawaii.
SHARPLESS, N. E. (1981). Personal communication.
STAM, C. H. (1972). *Acta Cryst.* B**28**, 2936–2945.
STEWART, R. F., DAVIDSON, E. R. & SIMPSON, W. T. (1965). *J. Chem. Phys.* **42**, 3175–3187.
THACKERAY, M. M. & GAFNER, G. (1974). *Acta Cryst.* B**30**, 1711–1714.
THACKERAY, M. M. & GAFNER, G. (1975). *Acta Cryst.* B**31**, 335–338.
WALD, G. (1968). *Science*, **162**, 230–239.
WILSON, A. J. C. (1949). *Acta Cryst.* **2**, 318–321.

Acta Cryst. (1981). B**37**, 2205–2209

Structures of Inorganic Rings as Antitumor Agents. I. Structure of the Two Allotropic Varieties of 1,3,3,5,5-Penta(1-aziridinyl)-1λ^6,2,4,6,3,5-thiatriazadiphosphorine 1-Oxide, $(NPaz_2)_2(NSOaz)$

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Abstract

The two allotropic varieties of the title compound $N_3P_2SO(NC_2H_4)_5$ have been studied; they are respectively named SOaz(I) and SOaz(II). SOaz(I) crystallizes in the orthorhombic system, space group $P2_12_12_1$, with a = 8·972 (1), b = 23·547 (2), c = 8·028 (1) Å, and Z = 4, V = 1696 Å^3, d_m = 1·40 (5), d_x = 1·419 Mg m^{-3}, μ(Mo $K\alpha$) = 0·39 mm^{-1}, m.p. = 357 K. SOaz(II) is monoclinic, $P2_1/c$, with a = 15·614 (4), b = 14·151 (6), c = 16·310 (6) Å, β = 114·7 (1)°, and Z = 8, V = 3274 Å^3, d_m = 1·45 (5), d_x = 1·471 Mg m^{-3}, μ(Mo $K\alpha$) = 0·41 mm^{-1}, m.p. = 376 K. Both structures have been determined using direct methods and refined to conventional R factors of 0·051 [SOaz(I)] and 0·035 [SOaz(II)] for 1492 and 2242 reflections respectively. SOaz(I) contains one type of $N_3P_2SO(NC_2H_4)_5$ molecule, and SOaz(II) two types, A and B; these three different types of molecule exhibit drastic changes in their conformation. This last fact is explained by the possible rotation around the (P–N) and (S–N) bonds which link the aziridinyl groups to the six-membered ring N_3P_2S.

Introduction

The antitumor activity of some thiatriazadiphosphorines belonging to the $(NPaz_2)_2(NSOX)$ family, namely SOF (X = F), SOPh (X = phenyl) and SOaz (X = az = aziridinyl) against P388 and L1210 leukemias and B16 melanoma has been reported recently (Labarre, Sournies, van de Grampel & van der Huizen, 1979; Sournies, 1980).

Some preliminary studies of the pharmalogical and toxicological behavior of these new antitumor agents have shown that (i) they induce neither mutagenicity (Ames tests) nor teratogenicity (on amphibians) and (ii) that they do not need any peculiar metabolization to be effective *in vivo*. Whereas (i) is of main interest for future clinical trials on humans, (ii) induced us to investigate the possible relationship between the *in vitro* geometric structure and the *in vivo* activity of the drugs.

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