hydrochloride instead of as DNP derivatives. The results of reactions 1b, 1c, and 1d are shown in Table I.

Registry No.—I (R = Me, R′ = (*R*)-(+)-Me), 37696-13-2; I (R = Me, R′ = (*S*)-(−)-Me), 37696-14-3; I (R = Me, R′ = (*R*)-(+)-Et), 37696-15-4; I (R = Me, R′ = (*R*)-(+)-Naph), 37696-16-5; I (R = Et, R′ = (*R*)-(+)-Me), 37696-17-6; I (R = Et, R′ = (*S*)-(−)-Me), 37696-18-7; I (R = Et, R′ = (*R*)-(+)-Et, 37696-19-8; I (R = Et, R′ = (*R*)-(+)-Naph), 37696-20-1; I (R = *i*-Pr, R′ = (*R*)-(+)-Me), 6397-96-2; I (R = *i*-Pr, R′ = (*S*)-(−)-Me), 6397-97-3; I (R = *i*-Pr, R′ = (*R*)-(+)-Et), 37696-23-4; I (R = *i*-Pr, R′ = (*R*)-(+)-Naph), 37696-24-5; I (R = *i*-Bu, R′ = (*R*)-(+)-Me), 27482-979; I (R = *i*-Bu, R′ = (*S*)-(−)-Me), 27482-980; I (R = *i*-Bu, R′ = (*R*)-(+)-Et), 37696-27-8; I (R = *i*-Bu, R′ = (*R*)-(+)-Naph), 37696-28-9; *N*-(*R*)-(+)-Me-Ala (DL), 37696-29-0; *N*-(*R*)-(−)-Me-But (DL), 37696-30-3; *N*-(*R*)-(+)-Me-Val (DL), 37696-31-4; *N*-(*R*)-(+)-Me-Leu (DL), 37696-32-5; D-Ala, 338-69-2; D-But, 2623-91-8; D-Val, 640-68-6; D-Leu, 328-38-1; D-Ala (DNP), 10580-45-7; D-But (DNP), 6367-34-6; D-Val (DNP), 37696-35-8; D-Leu (DNP), 37696-36-9.

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Structure and Conformation of Chalcone Photodimers and Related Compounds

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Based on combined evidence from various techniques, we report here the configurational assignments and the conformational preferences of the two chalcone (benzalacetophenone) photodimers. Mass spectra and nmr data have provided much of the evidence for the configurational assignments, while dipole moment data and conformational energy estimates have been used in the conformational work. Detailed analysis of mass and nmr spectra has allowed to assign the β-truxinic structure to the low-melting (mp 126°) photodimer and the α-truxillic structure to the high-melting (mp 226°) photodimer. These results modify previous reports which assigned the δ-truxinic structure to the low-melting isomer. The conformational properties of these molecules have been investigated by comparing the experimental dipole moments with contour maps of calculated dipole moments as a function of the internal rotation angles, and with conformational energy maps. Our results show that these structurally crowded molecules experience drastic restrictions of the conformational space available, so that they exist in well-defined, thermodynamically preferred conformations.

Owing to the widespread activity in the field of photodimerization reactions, structural studies on compounds containing cyclobutane rings recently attracted wide interest. Furthermore, photodimerization of unsaturated compounds often yields crowded cyclobutanes which may possess interesting conformational properties.

In the following, we report a study of the structure and conformational preferences of the two chalcone photodimers. Although the above compounds have been long known,[1] their stereochemistry has not been worked out in detail and we have combined several techniques to investigate the various aspect of the problem.

Evidence for a correct configurational assignment is here obtained by combining the mass and nmr data relative to the two photodimers, and comparing these data with those relative to a number of related compounds of known structure. The (novel) chlorinated derivatives of the two chalcone photodimers proved useful both in the elucidation of the mass spectra and in the interpretation of the dipole moment data.

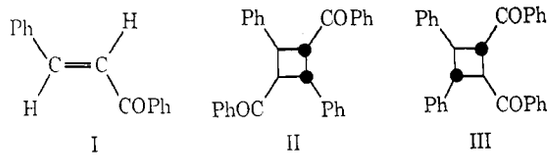
Dipole moment data and conformational energy estimates have been used to detect the conformational preferences of the photodimers.

Dipole moment data, being conformation dependent, may prove very useful in conformational studies but often do not provide unequivocal information, since different conformations may be calculated to have the same dipole moment value.[2] We have therefore found it desirable to generate a conformational energy contour map for each compound and to show that the calculated dipole moment corresponding to the energetically allowed region (preferred conformation) fits the experimental dipole moment.

Structural Assignments

Irradiation of chalcone (I) is known to produce a dimer the structure of which depends on the reaction phase employed.[1]

The high-melting (mp 226°) isomer, produced by solid-state irradiation, has been assigned[3] a structure II, while the low-melting (mp 126°) isomer, produced in solution, has been assigned[3] a structure III.



I II III

These assignments, however, were based on a complex series of chemical reactions in which the possibility of isomerizations was not eliminated, so that they appear tentative[4] at best.

(1) H. Stobbe and K. Bremer, *J. Prakt. Chem.*, **123**, 1 (1929).

(2) G. Montaudo, S. Caccamese, and P. Finocchiaro, *J. Amer. Chem. Soc.*, **93**, 4202 (1971).

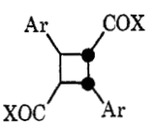
(3) P. Adler, Thesis, Rostock, 1938; *Chem. Abstr.*, **37**, 345 (1943).

(4) R. O. Kan, "Organic Photochemistry," McGraw-Hill, New York, N. Y., 1966, p 167.

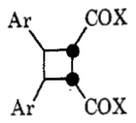
The problem has later received little attention, and the earlier[3] assignments have been incorporated in the most recent literature[5] without being subject to further scrutiny.

We have therefore reexamined the stereochemical problem by combining the mass and nmr data relative to the two photodimers and comparing these data with those relative to a number of structurally related compounds (Chart I).

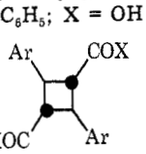
CHART I



II, Ar = C_6H_5; X = C_6H_5
V, Ar = C_6H_5; X = CH_3
VI, Ar = p-ClC_6H_4; X = CH_3
VII, Ar = p-ClC_6H_4; X = C_6H_5
IX, Ar = C_6H_5; X = OH



IV, Ar = C_6H_5; X = C_6H_5
VIII, Ar = p-ClC_6H_4; X = C_6H_5
XI, Ar = C_6H_5; X = OH



X, Ar = C_6H_5; X = OH

XII, Ar = C_6H_5; X = OH

Our results confirm the α-truxillic structure (II) of the high-melting isomer, but assign a β-truxinic structure (IV) to the low-melting isomer, contrary to the earlier report of a δ-truxinic structure (III).

Fragments arising from cyclobutane ring cleavage in the mass spectra of II and VII or IV and VIII, respectively, should allow us to differentiate between the head-to-tail (truxillic) and head-to-head (truxinic) structures. In fact, the three fragments XIII, XIV, and XV should be present in the case of a truxinic structure, but only XIV is expected in the case of a truxillic structure.

$[XC_6H_4CHCHC_6H_4X]\cdot^+$ XIII $[XC_6H_4CHCHCOC_6H_5]\cdot^+$ XIV

$[C_6H_5COCHCHCOC_6H_5]\cdot^+$ XV

X = H, Cl

The mass spectrum of VIII shows fragments XIII and XIV at m/e (rel intensity) 248 (8) and 242 (100), respectively. The third fragment XV is absent because of the primary loss of benzoyl from the molecular ion. Similarly, the mass spectrum of IV shows fragments XIII and XIV at m/e 180 (28), 179 (39), 178 (26) and 208 (50), 207 (65), respectively, which confirm the truxinic (head-to-head) structure of photodimers IV and VIII. On the contrary, the mass spectrum of VII shows *only* the fragment XIV at m/e (rel intensity) 242 (30) produced by the fragmentation of a truxillic (head-to-tail) structure. In the mass spectrum of II (the parent compound of VII), beside fragment XIV at m/e (rel intensity) 208 (66), 207 (84), fragment XIII is also present at m/e (rel intensity) 180 (4), 179 (12).

However, fragment XIII is generated here starting from XIV by a rearrangement process[6,7] with loss of carbon monoxide. Remarkably, in the case of the chlorinated derivative VII, the latter process does not provide a fragment with the same m/e value of XIII, so that the diagnosis of a truxillic structure for the photodimers II and VII is unequivocal.

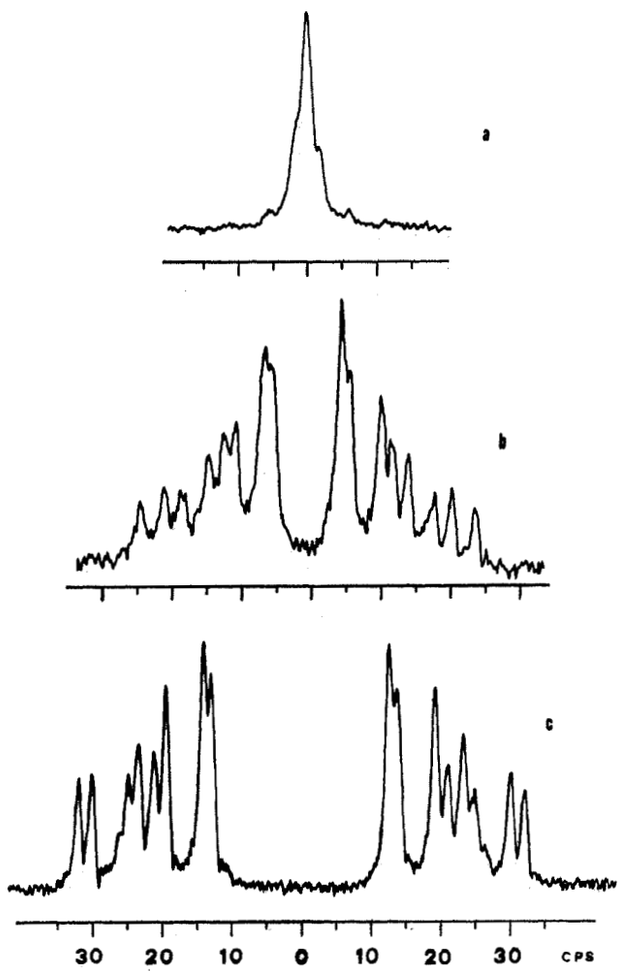


Figure 1.—Nmr spectra (cyclobutyl protons) of (a) benzalacetophenone photodimer II in $CDCl_3$; (b) benzalacetophenone photodimer II in $CDCl_3$ plus $Eu(fod)_3$; $Eu(fod)_3$/substrate = 0.25 mol/mol; (c) benzalacetone photodimer V in $CDCl_3$.

Furthermore, the mass spectra of V and VI show clearly that cyclobutane cleavage generates only fragment XVI, characteristic of a head-to-tail structure [for compound V at m/e (rel intensity) 146 (37), 145 (62) and for compound VI at m/e (rel intensity) 180 (67), 179 (30)]. Remarkably, no rearrangement process with loss of carbon monoxide occurs in the latter compounds.

$[XC_6H_4CHCHCOCH_3]\cdot^+$ XVI X = H, Cl

Further insight on the stereochemistry of these compounds is provided by nmr data. The high-melting chalcone photodimer (II) shows a broad singlet for the cyclobutyl protons in the nmr spectrum (Figure 1). However, addition of $Eu(fod)_3$ shift reagent removes the four-proton degeneracy, revealing a typical AA′BB′ pattern (Figure 1) very similar to that of

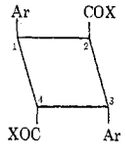
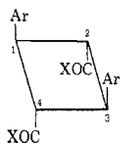
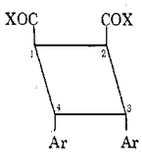
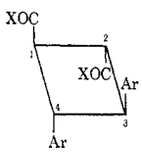
(5) H. Wynberg, M. B. Groen, and R. N. Kellogg, *J. Org. Chem.*, **35**, 2828 (1970).

(6) J. H. Beynon, G. R. Lester, and A. E. Williams, *J. Phys. Chem.*, **63**, 1861 (1959).

(7) J. H. Bowie, R. Grigg, D. H. Williams, S. O. Lawesson, and G. Schroll, *Chem. Commun.*, 403 (1965).

TABLE I

NMR DATA FOR CYCLOBUTANE RING PROTONS

	Ar	X	Compd	Chemical shifts, ppm $H_{2,4}$	$H_{1,3}$	$H_{1,2}$	$H_{3,4}$	Coupling constants, Hz $^3J_{2,3}$	$^3J_{1,2}$	$^4J_{1,3}$
	C_6H_5	OH	IX[a]	3.80	4.22			6.3	11.7	
	C_6H_5	CH_3	V	3.85	4.60			6.6	11.4	
	p-ClC_6H_4	CH_3	VI	3.86	4.61					
	C_6H_5	C_6H_5	II	4.90	4.90			6.0	11.9	
	p-ClC_6H_4	C_6H_5	VII	4.83	4.83					
	C_6H_5	OH	X[a]	3.22	3.78			9.3	9.3	
	C_6H_5	OH	XI[a]			3.96	4.57	7.85		−0.65
	C_6H_5	C_6H_5	IV			4.05	4.68	7.9		−0.4
	p-ClC_6H_4	C_6H_5	VIII			3.93	4.56			
	C_6H_5	OH	XII[a]			3.24	3.62	8.9		0.9

[a] Pyridine spectrum.

benzalacetone photodimer (V), for which a α-truxillic structure has already been demonstrated.[8,9]

The pattern of the signals for the cyclobutyl protons of the low-melting chalcone photodimer (IV) is also typical of an AA′BB′ system, which requires either a plane or a twofold axis of symmetry in the molecule.

The spectral patterns of the chloro derivatives VI, VII, and VIII, closely resemble those of the respective parent compounds (Table I).

From the relationship between the magnitude of the vicinal coupling constants and dihedral angles (Karplus equation) it should be possible to determine the stereochemistry of the cyclobutyl ring substituents by deriving the values of the cis and trans vicinal couplings (^3J) from the analysis of the spectra. However, vicinal couplings in cyclobutyl systems have been found to be sensitive to substituents and strain effects.[10-13] Furthermore, they vary over a sufficient range so that some overlap between the values occurs.[10-13]

On the contrary, both theoretical[14] and experimental[10,11,12,15] evidence has been provided showing that the cis diagonal couplings (^4J) are positive, while the trans diagonal couplings have a negative sign in cyclobutyl systems.

Under these circumstances, we have attempted to obtain unequivocal stereochemical assignments by comparing the nmr cyclobutyl protons data of the chalcone photodimers with those relative to four dimers derived from *trans*-cinnamic acid (Table I, compounds IX, X, XI, XII) and to the benzalacetone photodimer (Table I, compound V), for which the cyclobutyl protons appear as a symmetric AA′BB′ system. The $^3J_{1,2}$, $^3J_{2,3}$, $^4J_{1,3}$ coupling constants for compounds in Table I were obtained from the analysis of their AA′BB′ subspectra.[16-18]

The α-truxillic structure of the high-melting chalcone photodimer (II) results from the close agreement of the $J_{1,2}$ and $J_{2,3}$ coupling constants with those corresponding to the α-truxillic acid (IX) and to the benzalacetone photodimer (Table I, compound V, Figure 1). The alternative ϵ-truxillic structure (X) can be ruled out since $J_{1,2}$ and $J_{2,3}$ should be equal in this case. It is interesting to note that no stereochemical deductions[5] could be based on the comparison of the chemical shift values of compound II with those of the other α-truxillic compounds (Table I), or on the appearance of its undoped spectrum (Figure 1). In fact, substitution of the hydroxyl or methyl group with a phenyl provokes in II a sensible downfield shift of the methine protons geminal to the carbonyls,[19] so that the system appears as a broad singlet at 4.90 ppm. Conformational factors seem to be responsible for

(8) J. Dekker and T. G. Dekker, *J. Org. Chem.*, **33**, 2604 (1968).
(9) G. Montaudo and S. Caccamese, *J. Mol. Struct.*, **12**, 488 (1972).
(10) V. Georgian, L. Georgian, and A. V. Robertson, *Tetrahedron*, **19**, 1219 (1963).
(11) C. H. Krauch, S. Farid, and G. O. Schenck, *Chem. Ber.*, **99**, 625 (1966).
(12) I. Fleming and D. H. Williams, *Tetrahedron*, **23**, 2747 (1967).
(13) L. Paolillo, H. Ziffer, and O. Buchardt, *J. Org. Chem.*, **35**, 38 (1970).
(14) M. Barfield, *J. Amer. Chem. Soc.*, **93**, 1066 (1971).
(15) A. Gamba and R. Mondelli, *Tetrahedron Lett.*, 2133 (1971).
(16) D. M. Grant, R. C. Hirst, and H. S. Gutowsky, *J. Chem. Phys.*, **38**, 470 (1963).
(17) J. W. Emsley, J. Feeney, and L. H. Sutcliffe, "High Resolution Nuclear Magnetic Resonance Spectroscopy," Vol. I, Pergamon Press, London, 1965, p 347.
(18) E. Lustig, E. P. Ragelis, N. Duy, and J. A. Ferretti, *J. Amer. Chem. Soc.*, **89**, 3953 (1967).
(19) The signal at 3.80 ppm in the α-truxillic acid can be assigned to the 2,4-cyclobutyl protons (Table I), based on the fact that the methine proton in isopropyl phenyl ketone resonates at 3.58 ppm.[20] This applies also to the benzalacetone photodimer, This assignment was confirmed by the analysis of some lanthanide-induced shifts data which could not be fitted on the alerntive hypothesis.[21]
(20) "High Resolution NMR Spectra Catalog, Vol. 2, Varian Associates, Palo Alto, Calif., 1963, Spectrum No. 559.
(21) G. Montaudo and S. Caccamese, to be published.

TABLE II
DIPOLE MOMENT DATA[a] IN BENZENE AT 25° OF CHALCONE PHOTODIMERS AND RELATED COMPOUNDS

Compd	a_ϵ	a_n	μ, D
IV	2.17	0.326	2.66
VIII	2.95	0.296	3.44
II	1.26	0.338	1.88
VII	1.57	0.292	2.39
V[b]	1.34	0.188	1.76

[a] $a_\epsilon = [(\epsilon_{12} - \epsilon_1)/w_2]_{w_2 \to 0}$, $a_n = [(n_{12}^2 - n_1^2)/w_2]_{w_2 \to 0}$; ϵ is the dielectric constant of the solvent; ϵ_{12} is the dielectric constant of the solution, w_2 is the weight fraction of solute, n_1 is the refractive index of the solvent, and n_{12} is the refractive index of the solution; final formula of the Guggenheim procedure (see ref 2), $\mu = [0.009208 M_2 (a_\epsilon - a_n)]^{1/2}$. [b] Reference 9.

this downfield shift, as will be discussed in the next section.

Also the β-truxinic structure of the low-melting chalcone photodimer (IV) results from the close agreement (Table I) of the $^3J_{2,3}$ and $^4J_{1,3}$ coupling constants with those corresponding to the β-truxinic acid (XI) (the AA'BB' spectral patterns of the two compounds are practically superimposable). The alternative δ-truxinic structure (III) can be ruled out because of the negative sign of the $^4J_{1,3}$ constant (which indicates a trans-1,3 structure) instead of the positive value of $^4J_{1,3}$ expected for a cis-1,3 structure.

Conformational Properties

The intriguing conformational properties of the two chalcone photodimers II and IV become evident when one considers that such crowded molecules are likely to experience a drastic restriction of the conformational space available to the internal rotation of the cyclobutane substituents.

However, from the inspection of the structural models in Figure 2 one may easily realize that these molecules have several independent conformational parameters and that they are complex systems, difficult to deal with.

In spite of their complexity, the conformational properties of the two photodimers can be properly investigated by comparing the experimental dipole moments (DM) with contour maps of calculated DM as a function of the internal rotation angles, and with conformational energy contour maps.[9,22] We need a simplifying assumption to start our analysis. We shall assume a planar form for the cyclobutane ring in compounds II and IV, as found in the solid state for several 1,2,3,4-tetrasubstituted cyclobutyl derivatives.[23,24] Later, it will be seen how we can actually verify the validity of this assumption.

The experimental DM values for the compounds investigated are collected in Table II. Inspection of the structural models in Figure 2 reveals that the overall DM of the photodimers varies with the molecular conformation, since a variation of the internal rotation angles ϑ_1 and ϑ_2 causes a change in the relative orientation of the two carbonyl groups.

Contour maps of the calculated DM as a function of ϑ_1 and ϑ_2 are reported in Figures 3 and 4 for the

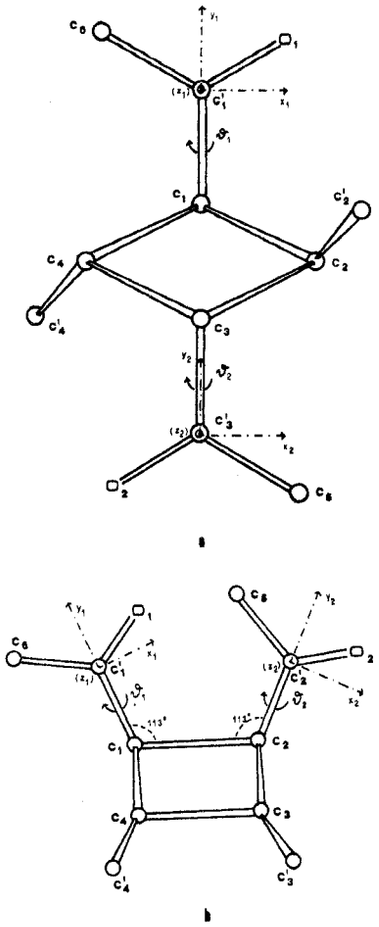


Figure 2.—Structural models and internal rotation angles of compound II (a) and compound IV (b).

photodimers II and IV, respectively. Dipole moments were calculated, for each pair of ϑ_1 and ϑ_2 values, adding vectorially the bond moments resolved into their x, y, and z components. The individual moment contributed by each carbonyl group was taken as 2.96 D[25] and its direction was assumed to be that of the C–O bond. Interatomic distances and bond angles were deduced from pertinent literature data and the cyclobutane ring was assumed to be planar.[23,24] The contour maps were generated starting from the conformations in Figure 2 and rotating the carbonyl groups clockwise; for compound II (Figure 2a) the two C–O bonds lie in parallel planes with respect to the xy (paper) plane at 45° with the $C_1'C_1C_2$ and $C_3'C_3C_4$ planes, respectively; for compound IV (Figure 2b) the two C–O bonds lie in the paper plane.

The experimental DM values for compounds II (1.88 D) and IV (2.66 D) are well below the DM values corresponding to the completely free rotation of the benzoyls (II, 3.62 D; IV 4.54 D, respectively), indicating that these molecules are likely to experience restricted rotation. However, at this stage, DM data alone are insufficient to solve unequivocally the conformational problem, since the experimental DM values of II and IV can be fitted over large regions of the maps of calculated DM in Figures 3 and 4. We have therefore attempted to complement these data with some *a priori* conformational energy estimates.

(22) G. Montaudo, P. Finocchiaro, P. Maravigna, and C. G. Overberger, *Macromolecules*, **5**, 197 (1972).
(23) C. Chang, R. F. Porter, and S. H.Bauer, *J. Mol. Struct.*, **7**, 89 (1971).
(24) T. N. Margulis, *J. Amer. Chem. Soc.*, **93**, 2193 (1971).
(25) G. Montaudo, P. Finocchiaro, and P. Maravigna, *ibid.*, **93**, 4214 (1971).

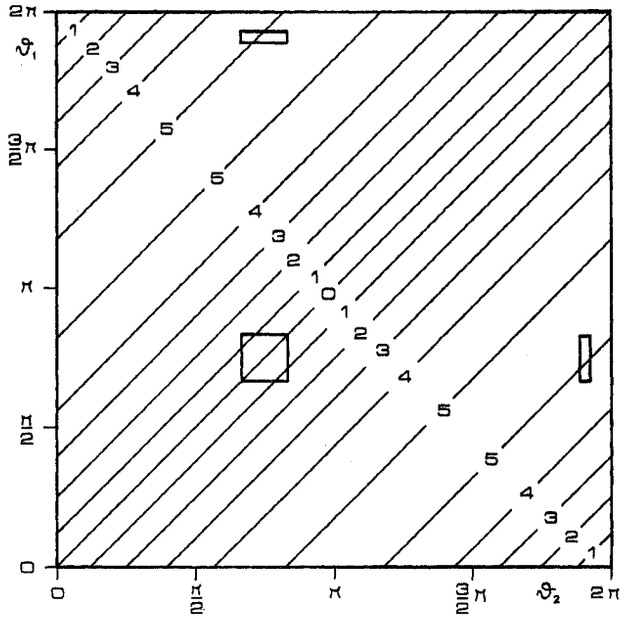


Figure 3.—Contour map of calculated dipole moment as a function of ϑ_1 and ϑ_2 internal rotation angles and, overlapped, conformationally allowed area for compound II.

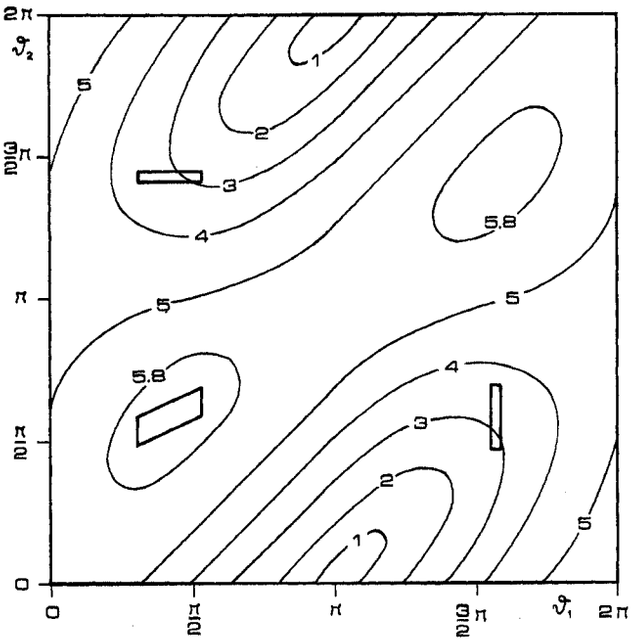


Figure 4.—Contour map of calculated dipole moment as a function of ϑ_1 and ϑ_2 internal rotation angles and, overlapped, conformationally allowed area for compound IV.

The contour maps of conformational energy relative to compounds II and IV are shown overlapping the dipole moments maps in Figures 3 and 4, respectively.[26] Only nonbonded interactions were included in this estimate. Coefficients for the pairwise Lennard-Jones potential interaction were taken from Schott and Scheraga.[27] Angular deformations, torsional potentials, and electrostatic interactions were not evaluated, so that an "exclusion map"[28] has actually been obtained and only the line delimiting the energetically allowed area is shown in the figures. The maps were generated using Dreiding models, an approximation justified by the above assumptions.[29]

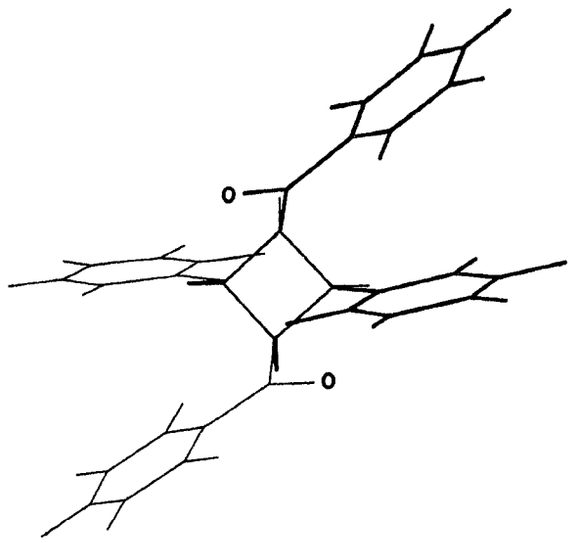


Figure 5.—Preferred conformation of compound II viewed along an axis normal to the cyclobutane ring.

On evaluating our results, it should be noted that for the photodimer II the experimental DM value (1.88 D, Table II) can be fitted over a wide region of the DM contour map, but only two narrow regions of the conformational space are available to the molecule on energetic grounds (Figure 3).[31] Furthermore, only one of these regions ($\vartheta_1 \cong 145$, $\vartheta_2 \cong 145$) is compatible with the experimental DM value and it is therefore chosen as the preferred conformation (Figure 5). Remarkably, the benzalacetone photodimer V, which possess an α-truxillic structure as the chalcone photodimer II, has been found[9] to exist in the same conformation as II, and has a measured DM value of 1.76 D.[9] The preferred conformation of photodimer II (Figure 5) also accounts for the downfield shift observed in the nmr of II, as compared to V, of the methine protons geminal to the carbonyls. In fact, the phenyl groups are held in such a position to operate a deshielding effect on the methine protons (Figure 5). The conformational preference of the chlorinated photodimer VII should be identical with that of the parent compound II, since the chloro atoms are in a para position.

The individual moments contributed by the chlorine atoms in compound VII should cancel each other if the cyclobutane ring is fixed in the planar form. A small

(26) Actually, these molecules have four internal rotation angles. However, for compound II the rotation of the two phenyl groups is severely hindered (thermodynamically restricted rotation) so that they can be considered nearly fixed in the positions shown in Figure 5. In compound IV the internal rotation of the two phenyls does not interfere with that of the benzoyl groups. However, the two rings hinder each other; in Figure 6 they are represented in one of the two *equivalent* positions that they can assume (the other is enantiomeric).

(27) R. A. Schott and H. A. Scheraga, *J. Chem. Phys.*, **45**, 2091 (1966); **46**, 4410 (1967).

(28) P. J. Flory, "Statistical Mechanics of Chain Molecules," Interscience, New York, N. Y., 1969, p 253, and references cited therein.

(29) The energetically allowed regions in Figures 5 and 6 are slightly underestimated, since angular deformations of the bonds were neglected in generating the maps. Furthermore, the wideness of the allowed area is also function of the value of the carbonyl–phenyl torsional angle. On the basis of the existing literature data,[30] we have selected a value of 30°, which also permits generation of the widest allowed area possible. It should be remarked that, given the extremely narrow regions energetically allowed, the assumptions made in generating the energy maps are unlikely to affect significantly the accuracy of our analysis.

(30) A. G. Pinkus and H. C. Custard, *J. Phys. Chem.*, **74**, 1042 (1970), and references cited therein.

(31) Actually, three regions are shown as allowed in Figure 3, but the two regions centered at $\vartheta_1 \cong 350$, $\vartheta_2 \cong 145$ and $\vartheta_1 \cong 145$, $\vartheta_2 \cong 350$, respectively, are enantiomeric.

difference (0.51 D, Table II) is actually measured between the two compounds, which seems to indicate either a certain degree of puckering or a libration of the ring around the planar form. Alternatively, one could attribute the DM difference to local field effects generated by the polar chlorine atoms. We favor the idea that to consider the cyclobutane ring as being planar is sufficiently accurate in the present case.

The conformational preference of the β-truxinic photodimer IV can be assigned by an analysis entirely similar to that carried out in the case of II. Data in Figure 4 show that the energetically allowed regions are very narrow; only one of them ($\vartheta_1 \cong 75$, $\vartheta_2 \cong 260$)[32] is compatible with the experimental DM value (Table II) and it is therefore chosen as the preferred conformation (Figure 6). Interestingly, in the two rotamers of this conformation, the two vicinal benzoyls are enantiotopic and therefore must exchange.

Also in this case the conformational preference of the chlorinated derivative VIII should be identical with that of the parent compound IV. However, the overall DM value here is influenced by the chlorine substitution and the conformational preference of VIII cannot be simply deduced by comparing its experimental DM value with that of the unsubstituted photodimer II.

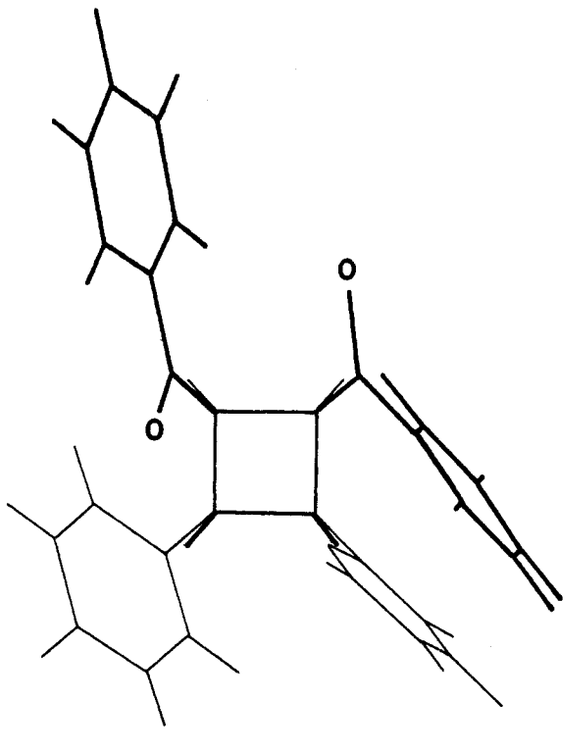


Figure 6.—Preferred conformation of compound IV viewed along an axis normal to the cyclobutane ring.

Experimental Section

Uv spectra were recorded in 95% ethanol on a Hitachi Perkin-Elmer EPS-3T spectrophotometer. The ir spectra were determined in Nujol using a Perkin-Elmer 237 spectrophotometer. The nmr spectra were obtained in deuteriochloroform (unless otherwise indicated) with a Varian A-60D instrument using tetramethylsilane as the internal standard. They are reported in parts per million on the δ scale. Eu(fod)$_3$ (Sievers reagent[33]) obtained from Alfa Inorganics was used without further purification. The mass spectra were obtained at 70 eV by direct injection into the ion source of a Varian MAT CH 7 mass spectrometer. The dielectric constants were measured in benzene (99.9% Schuchardt, dried over molecular sieves) at 25 ± 0.02° with a DM 01 Dipolmeter WTW working at 2 MHz. For the refractive index measurements a differential refractometer BP 2000 V Brice-Phoenix was used, which measured the difference in refractive index between a solution and benzene as solvent, at 25°. From these data, dipole moments have been calculated by a technique previously described.[2] Molecular weight determinations were obtained by vapor phase osmometry, in *o*-dichlorobenzene at 130° using a Mechrolab 302 thermoelectric osmometer. Melting points (uncorrected) were obtained in glass capillary tubes sealed under vacuum.

Synthetic Procedures.—The following α,β-unsaturated ketones were prepared according to the literature: benzalacetone,[34] *p*-chlorobenzalacetone,[35] benzalacetophenone,[34] *p*-chlorobenzalacetophenone.[36] According to the literature also these acids were prepared: α-truxillic acid,[37] ε-truxillic acid,[38] β-truxinic acid,[39] δ-truxinic acid.[40]

The irradiation experiments were carried out using a Q 1200 Quarzlampengesellschaft (Hanau, West Germany) medium-pressure mercury lamp. For solid-state photodimerization the powdered compounds were irradiated in air from 30 cm with a Pyrex-jacketed lamp, to cut off lower wavelengths. For solution photodimerization, the solution of the compounds, previously bubbled with nitrogen, was exposed to the radiation of the unfiltered lamp in a Pyrex flask placed at a distance of 40–50 cm. Reaction was monitored during irradiation by uv spectra. Using this irradiation apparatus, the following photodimers were prepared: *trans,cis,trans*-1,3-diacetyl-2,4-diphenylcyclobutane (V),[40] *trans,cis,trans*-1,3-dibenzoyl-2,4-diphenylcyclobutane (II),[1] *trans,cis,trans*-1,4-diphenyl-2,3-dibenzoylcyclobutane (IV).[1]

***trans,cis,trans*-1,3-Diacetyl-2,4-di(4-chlorophenyl)cyclobutane (VI).**—*p*-Chlorobenzalacetone (10 g) was irradiated in the solid state. After 60 days, the brownish material was dissolved in acetone and chromatographed over silica gel. Elution with hexane–acetone (9:1) afforded several central fractions which showed no fluorescence to Wood light by tlc. Evaporation of the solvent and recrystallization from hexane gave 100 mg of a compound melting at 194–196°: ν_{CO} 1700 cm^{-1}; mol wt calcd for $C_{20}H_{18}Cl_2O_2$, 361.3; found, 358.0.

***trans,cis,trans*-1,3-Dibenzoyl-2,4-di(4-chlorophenyl)cyclobutane (VII).**—*p*-Chlorobenzalacetophenone (5 g) was irradiated in the solid state. After 22 days, the yellow-orange product was crystallized from an ethanol–dioxane mixture as white crystals (400 mg): mp 257–259°; ν_{CO} 1671 cm^{-1}; mol wt calcd for $C_{30}H_{22}Cl_2O_2$, 485.4; found, 470.1.

***trans,cis,trans*-1,4-Di(4-chlorophenyl)-2,3-dibenzoylcyclobutane (VIII).**—A solution of *p*-chlorobenzalacetophenone (7 g) in 25 ml of chloroform was irradiated, adding a crystal of iodine, for 9 days in a Pyrex flask. The solvent was evaporated as the yellow-orange residue, treated with a mixture of acetone–hexane, and chromatographed over silica gel. Elution with hexane–acetone (9:1) afforded several fractions, tested by tlc. Similar fractions were collected and concentrated. On standing, 300 mg of a white powder precipitated. Recrystallization from ethanol gave white crystals: mp 113–114°; ν_{CO} 1689, 1666 cm^{-1}; mol wt calcd for $C_{30}H_{22}Cl_2O_2$, 485.4; found, 478.2.

All the compounds studied analyzed correctly by elemental analysis.

Mass Spectra.—Only significant peaks are reported (m/e > 164). For chlorinated compounds only the lowest ions of the isotopic clusters are given: VI, 360, 342, 317, 302, 180, 165, 145; VII, 484, 466, 379, 365, 242, 214, 207, 179, 165; II, 416, 398, 311, 296, 208, 207, 180, 179, 178, 165; VIII, 484, 466, 379, 248, 242, 214, 207, 179, 178, 165; IV, 416, 398, 311, 296, 208, 207, 180, 179, 178, 165.

(32) Actually, three regions are shown as allowed in Figure 4, but the two regions centered at $\vartheta_1 \cong 75$, $\vartheta_2 \cong 260$ and $\vartheta_1 \cong 260$, $\vartheta_2 \cong 75$, respectively, are enantiomeric.

(33) R. E. Rondeau and R. E. Sievers, *J. Amer. Chem. Soc.*, **93**, 1522 (1971).

(34) H. Gilman and A. H. Blatt, Ed., "Organic Syntheses," 2nd ed, Wiley, New York, N Y., 1941, pp 77–78.

(35) R. E. Lutz, T. A. Martin, J. F. Codington, T. M. Amacker, R. K. Allison, N. H. Leake, R. J. Rowlett, J. D. Smith, and J. W. Wilson, *J. Org. Chem.*, **14**, 982 (1949).

(36) E. Weitz and A. Scheffer, *Chem. Ber.*, **54**, 2327 (1921).

(37) A. Schönberg, "Preparative Organic Photochemistry," Springer-Verlag, Berlin, 1968, p 85.

(38) R. Stoermer and E. Emmel, *Chem. Ber.*, **53**, 497 (1920).

(39) R. Stoermer and F. Scholtz, *ibid.*, **54**, 85 (1921).

(40) A. Butenant, L. Karlson-Poschmann, G. Failer, U. Schiedt, and E. Biekert, *Justus Liebigs Ann. Chem.*, **575**, 123 (1952).

Nmr.—II, 4.90 (4 H), 7.23 (16 H), 7.77 (4 H); IV, 4.05–4.68 (4 H), 7.30 (16 H), 7.89 (4 H); V, 1.61 (6 H), 3.85–4.60 (4 H), 7.25 (10 H); VI, 1.70 (6 H), 3.86–4.61 (4 H), 7.33 (8 H); VII, 4.83 (4 H), 7.25 (14 H), 7.75 (4 H); VIII, 3.93–4.56 (4 H), 7.34 (14 H), 7.85 (4 H).

Registry No.—II, 24825-08-9; IV, 37676-14-5; V, 16607-22-0; VI, 37676-16-7; VII, 37676-17-8; VIII, 37676-18-9; IX, 490-20-0; X, 528-38-1; XI, 528-34-7; XII, 528-33-6; *p*-chlorobenzalacetone, 3160-40-5.

Neighboring-Group Participation in Carbohydrate Chemistry. IV.[1] Neighboring-Group Reaction of the 6-Benzamido Group in a Nucleophilic Displacement of a 5-Mesylate[2]

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The neighboring-group reaction of the 6-benzamido group in the nucleophilic displacement of a 5-mesylate was demonstrated. Refluxing of an *N*,*N*-dimethylformamide solution of 6-benzamido-6-deoxy-1,2-*O*-isopropylidene-3,5-di-*O*-methylsulfonyl-α-D-glucofuranose (**12**) with anhydrous potassium acetate gave a complex reaction mixture from which the following three products were isolated and characterized: 6-benzamido-6-deoxy-1,2-*O*-isopropylidene-3-*O*-methylsulfonyl-β-L-idofuranose (**15**, 5%), 2-phenyloxazoline derivatives of 6-amino-6-deoxy-1,2-*O*-isopropylidene-3-*O*-methylsulfonyl-β-L-idofuranose (**14b**, 41%), and 6-amino-3,6-dideoxy-1,2-*O*-isopropylidene-β-L-*threo*-hex-3-enofuranose (**22**, 18%). Heating of an ethanolic solution of **12** with 1 mol of sodium ethoxide gave **14b** (58%).

The neighboring-group participation of a carboxamido group in the nucleophilic displacement of an alkyl and/or aryl sulfonate bound to a vicinal carbon atom is an extensively studied reaction[3,4] which has been frequently utilized in carbohydrate chemistry for the synthesis of various amino sugar derivatives.[3,4] Either the carbonyl oxygen or the nitrogen atom of the carboxamido group (**1**) can function as the nucleophile in the reaction,[5] giving an oxazoline (**2**) or an aziridine (**3**) derivative as an intermediate. Whether the participation of the carboxamido group will occur with the formation of the five- (**2**) or three-membered ring intermediate (**3**) seems to be controlled by stereochemical factors. However, in some *N*-aryl substituted amides, an electronic factor may play an important role as well.[6] A recent report has described the participation of the *N*,*N*-dialkyl carboxamido group with the possible formation of an imino-α-lactone (**5**) or an α-lactam (**6**) intermediate.[7]

The apparent lack of participation of the 6-benzamido group when methyl 2,6-dibenzamido-2,6-dideoxy-3-*O*-methyl-5-*O*-methylsulfonyl-β-D-glucofuranoside (**7**) was treated with sodium benzoate in *N*,*N*-dimethylformamide, or sodium acetate in ethanol,[8] was rather surprising. Equally puzzling was the absence of participation of the 6-benzamido group in the reaction of 6-benzamido-6-deoxy-1,2-*O*-isopropylidene-3,5-di-*O*-methylsulfonyl-α-D-glucofuranose (**12**) and 6-benzamido-6-deoxy-1,2-*O*-isopropylidene-5-*O*-methylsulfonyl-α-D-glucofuranose (**13**) with sodium ethoxide in ethanol at elevated and/or room temperature.[9] Since the obtained syrups, which could not be purified, did not exhibit the NH absorption peak in the 3300–3200-cm^{-1} region in the infrared spectrum, Hough, *et al.*,[9] concluded that an ethyleneimine derivative was not formed. They assumed instead that elimination of the 5-*O*-methylsulfonyl group with a hydrogen atom from C-6 had occurred, since this was known to be a facile reaction.[10] The formation of the corresponding oxazoline derivative **14b** was not mentioned. The unexplainable absence of participation of the 6-benzamido group in the displacements described above prompted us to reinvestigate the whole problem. The obtained results are presented in this paper.

Results and Discussion

As a model substance for our studies, 6-benzamido-6-deoxy-1,2-*O*-isopropylidene-3,5-di-*O*-methylsulfonyl-α-D-glucofuranose (**12**)[9] was employed.

Refluxing of an *N*,*N*-dimethylformamide solution of **12** with anhydrous potassium acetate for 1 hr gave a complex reaction mixture, from which, after both column and preparative thin layer chromatography using 4:1 ether–benzene and 95:5 benzene–methanol solvent mixtures, three products were isolated and characterized.

The first product (**14**, 41%) was a white, crystalline solid, mp 132–133°, for which the infrared spectrum did not show an absorption peak in the 3300-cm^{-1} region, typical for the amide NH (NH stretch).[11a] However, there was a strong absorption band at 1650 cm^{-1}, indicative of either an amide carbonyl group (C=O stretch)[11a] or a carbon–nitrogen double bond (C=N stretch).[11b,12] Two bands at 1602 and 1580

(1) Part III: M. Miljković, D. Miljković, A. Jokić, V. Andrejević, and E. A. Davidson, *J. Org. Chem.*, **37**, 2536 (1972).

(2) This work was supported by a grant (AM12074) from the National Institute of Arthritis and Metabolic Diseases, National Institutes of Health, U. S. Public Health Service.

(3) L. Goodman, *Advan. Carbohyd. Chem.*, **22**, 127, 143 (1967).

(4) B. Capon, *Quart. Rev. Chem. Soc.*, **18**, 71 (1964).

(5) T. Taguchi and M. Kojima, *J. Amer. Chem. Soc.*, **81**, 4316 (1959).

(6) H. W. Heine, P. Love, and J. L. Bove, *ibid.*, **77**, 5420 (1955).

(7) M. Miljković, D. Miljković, A. Jokić, V. Andrejević, and E. A. Davidson, *J. Org. Chem.*, **36**, 3218 (1971).

(8) W. Meyer zu Reckendorf, *Tetrahedron*, **19**, 2033 (1963); *Angew. Chem.*, **75**, 573 (1963); L. Goodman, *Advan. Carbohyd. Chem.*, **22**, 137 (1967).

(9) D. H. Buss, L. D. Hall, and L. Hough, *J. Chem. Soc.*, 1616 (1965).

(10) R. E. Gramera, T. R. Ingle, and R. L. Whistler, *J. Org. Chem.*, **29**, 878 (1964).

(11) (a) N. B. Colthup, L. H. Daly, and S. E. Wiberley, "Introduction to Infrared and Raman Spectroscopy," Academic Press, New York, N. Y., 1964, p 263; (b) p 282; (c) p 224; (d) p 309.

(12) W. Meyer zu Reckendorf and W. A. Bonner, *Chem. Ber.*, **95**, 1917 (1962).