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PHOTOSENSITIZED [4+2] CYCLODIMERIZATIONS OF AROMATIC RETINOIDS[1]

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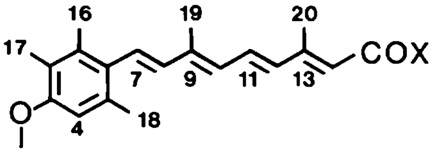
Abstract - Hematoporphyrin sensitized photoreactions of the aromatic retinoids ethyl (all-E)-9-(4-methoxy-2,3,6-trimethylphenyl)-3,7-dimethyl-2,4,6,8-nonatetraenoate 1a and (all-E)-N-ethyl-9-(4-methoxy-2,3-6-trimethylphenyl)-3,7-dimethyl-2,4,6,8-nonatetraenamide 1b in ethanolic solution were investigated. Using light λ ≥ 400 nm 1a and 1b yielded [4+2]-cyclodimers of (all-E)-type 2 ($2a_1$, $2a_2$, and $2b_2$, $2b_3$) with three different steric arrangements of the substituents on the newly formed cyclohexene rings. These photoproducts correspond to kitol, a known dimer of retinol. Irradiation of 1a with light of λ ≥ 365 nm gave $2a_1$ and the two (7'Z)-cyclodimers $3a_1$ and $3a_4$, the latter possessing a further stereochemistry on the cyclohexene. Whereas the structures $2a_1$ and $2a_2$ were determined by X-ray analyses, the structures $2b_2$, $2b_3$, $3a_1$, and $3a_4$ were elucidated by an extensive ^1H and ^{13}C NMR study including homo- and heteronuclear shift correlated 2D spectroscopy and nuclear Overhauser difference experiments. The deduced steric arrangement of the substituents on the generated cyclohexenes excludes synchronous [4+2]-cycloadditions. Therefore, we suggest a two step mechanism. Because the light absorption of 1a and 1b dominates that of the sensitizer, we assume an energy cascade from the directly excited substrates to the sensitizer and herefrom back to the substrates in their ground state.

INTRODUCTION

Aromatic retinoids of type 1 (Fig. 1) exhibit therapeutic effects against skin diseases like psoriasis and acne[2]. Recently, we have demonstrated that these compounds react photochemically in the solid state[3]. Depending on the crystal modifications of 1a different [2+2]-cyclodimers were obtained. It has also been shown previously[4] that direct irradiation of the monomer 1a in solution gave no dimers but only (Z)-isomers and 11 of 14 possible mono-, di-, and tri-(Z)-isomers could be isolated and identified.

We now report on results of the irradiation of 1a and 1b in ethanolic solution in the presence of hematoporphyrin as photosensitizer. We have chosen this sensitizer for the photochemical in vitro testing of drugs because it is structurally related to heme, the prosthetic group of hemoglobins and of a number of hemoproteins.



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Substrate	X	Generic Name
1a	OEt	Etretinate
1b	NHEt	Motretinide

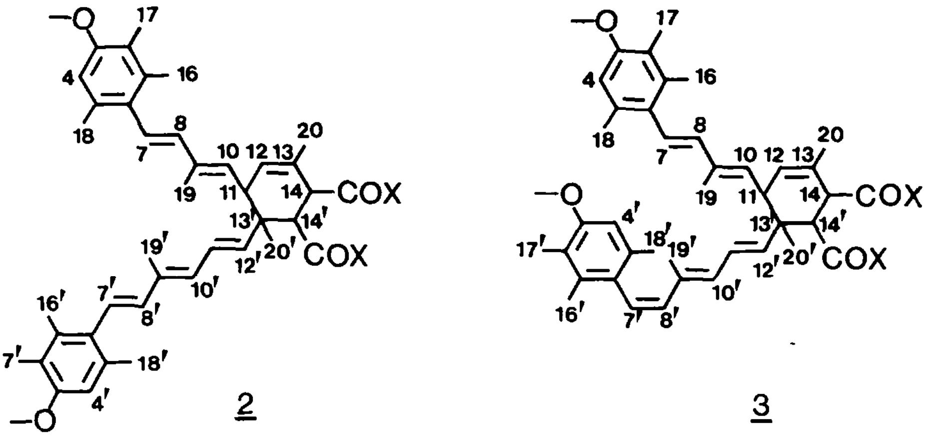
Figure 1. Substrates which undergo photosensitized [4+2]-dimerization in solution.- The numbering of the C-atoms does not follow IUPAC rules but was chosen in analogy to the vitamins A and carotenoids in order to simplify the comparison of their spectroscopic data.

Surprisingly, the photosensitized reactions of 1a and 1b exclusively yielded [4+2]-cyclodimers of type 2 and 3 (Fig. 2) and no monomeric (Z)-isomers. All these dimers contain a newly formed cyclohexene ring and 4 different types of stereochemical arrangement of the substituents were found which we distinguish in the following by the subscripts 1 to 4 as shown in Table 1.

Whereas the structures of the dimers (all-E)-$2a_1$ and (all-E)-$2a_2$ were elucidated by X-ray analyses, the structures of (all-E)-$2b_2$, (all-E)-$2b_3$, and the two (7'Z)-isomers were derived by extensive ^{1}H and ^{13}C NMR investigations including homo- and heteronuclear 2D COSY and 1D nuclear Overhauser (NO) difference experiments. The corresponding NMR experiments with $2a_1$ and $2a_2$ of known structure served as a reliable basis for the interpretation of the spectra of the four other isomers. The derivation of the structures and the photochemical implications with respect to the formation of the dimers will be discussed below.

RESULTS

Irradiation of 1a and of 1b with light $\lambda \geq 400$ nm gave (all-E)-dimers of the general formula 2. The latter corresponds to the structure of kitol[5,6,7] which is a retinol dimer and has been isolated from whale liver oil. The use of light $\lambda \geq 365$ nm led to dimers of the general formula 3 with (7'Z)-geometry. As yet retinol dimers of this type have not been described in the literature. The stereoscopic representations of the structures of $2a_1$ and $2a_2$ obtained by X-ray analyses are shown in Figures 5 and 6 (see Exp.Part). In contrast to these compounds the structures of the four additional isomers were derived by ^{1}H and ^{13}C NMR only. The spectral data of all dimers are summarized in the Exp.Part. Besides the (7'Z) configuration in $3a_1$ and $3a_4$ the dimers possess partly different sterochemistry of the cyclohexene ring as is depicted for all six cyclodimers in Table 1. The cyclohexene ring adopts a half-chair conformation as has been revealed by means of X-ray and ^{1}H NMR.

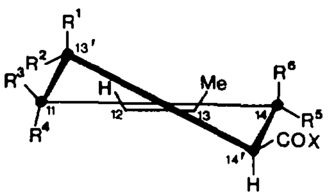


2 3

Figure 2. General formulae of the photodimers 2 and 3.

Table 1. Structures of the photodimers derived from 1a and 1b, respectively, with four different steric arrangements of the substituents on the newly formed cyclohexenes.

Substituents	Dimers $2a_1$/$3a_1$	Dimers $2a_2$/$2b_2$	Dimer $2b_3$	Dimer $3a_4$
R^1	(all-E)-/(7'Z)-$C_{17}H_{21}O$	Me	(all-E)-$C_{17}H_{21}O$	Me
R^2	Me	(all-E)-$C_{17}H_{21}O$	Me	(7'Z)-$C_{17}H_{21}O$
R^3	(all-E)-$C_{15}H_{19}O$	H	H	(all-E)-$C_{15}H_{19}O$
R^4	H	(all-E)-$C_{15}H_{19}O$	(all-E)-$C_{15}H_{19}O$	H
R^5	H	COOEt/CONHEt	CONHEt	H
R^6	COOEt	H	H	COOEt



For the elucidation of the structures of $\underline{2b}_2$, $\underline{2b}_3$, $\underline{3a}_1$, and $\underline{3a}_4$ by NMR the following general strategy was applied. Firstly, the homonuclear COSY 2D spectra were measured in order to deduce the assignments of the proton signals. Application of the long-range version of COSY with extra delays, enhancing cross-peaks caused by long-range couplings, has been found of great advantage here, since connectivities between protons over up to 7 bonds were detectable.

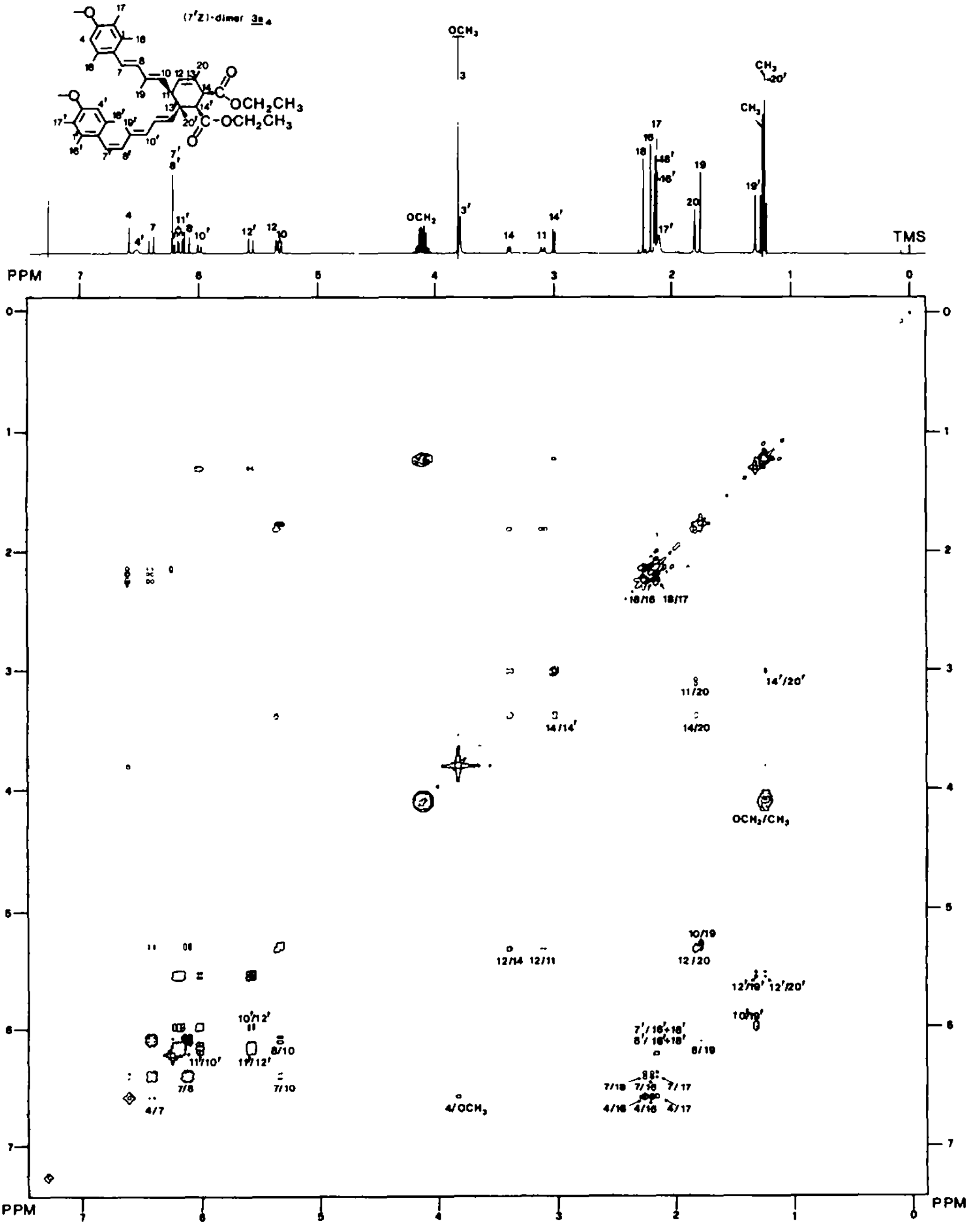


Figure 3: Top: 400 MHz ^{1}H-NMR of $\underline{3a}_4$. Bottom: 400 MHz proton-proton shift correlated 2D (COSY LR) of $\underline{3a}_4$ (approx. 1.5 mg in 0.5 ml CDCl$_3$); absolute value, symmetrized (for experimental parameters see Exp.Part).

This greatly simplified the assignments of the signals of the structurally similar side-chains of the dimers, though their chemical shift diffences were partly rather small. An example is shown in Fig. 3. As a further step the $^{1}H,^{13}C$ COSY in its one-bond version ($^{1}J_{CH}$~ 140 Hz) was acquired for all dimers in order to link the signals of the carbons and their directly attached protons. In the successive long-range $^{1}H,^{13}C$ COSY experiments (J_{CH}~ 8-10 Hz) the carbons and protons being 2 and 3 bonds apart could be correlated. These experiments gave relevant information on the connectivity of the different structural subunits of the dimers. A representative example is shown in Fig. 4.

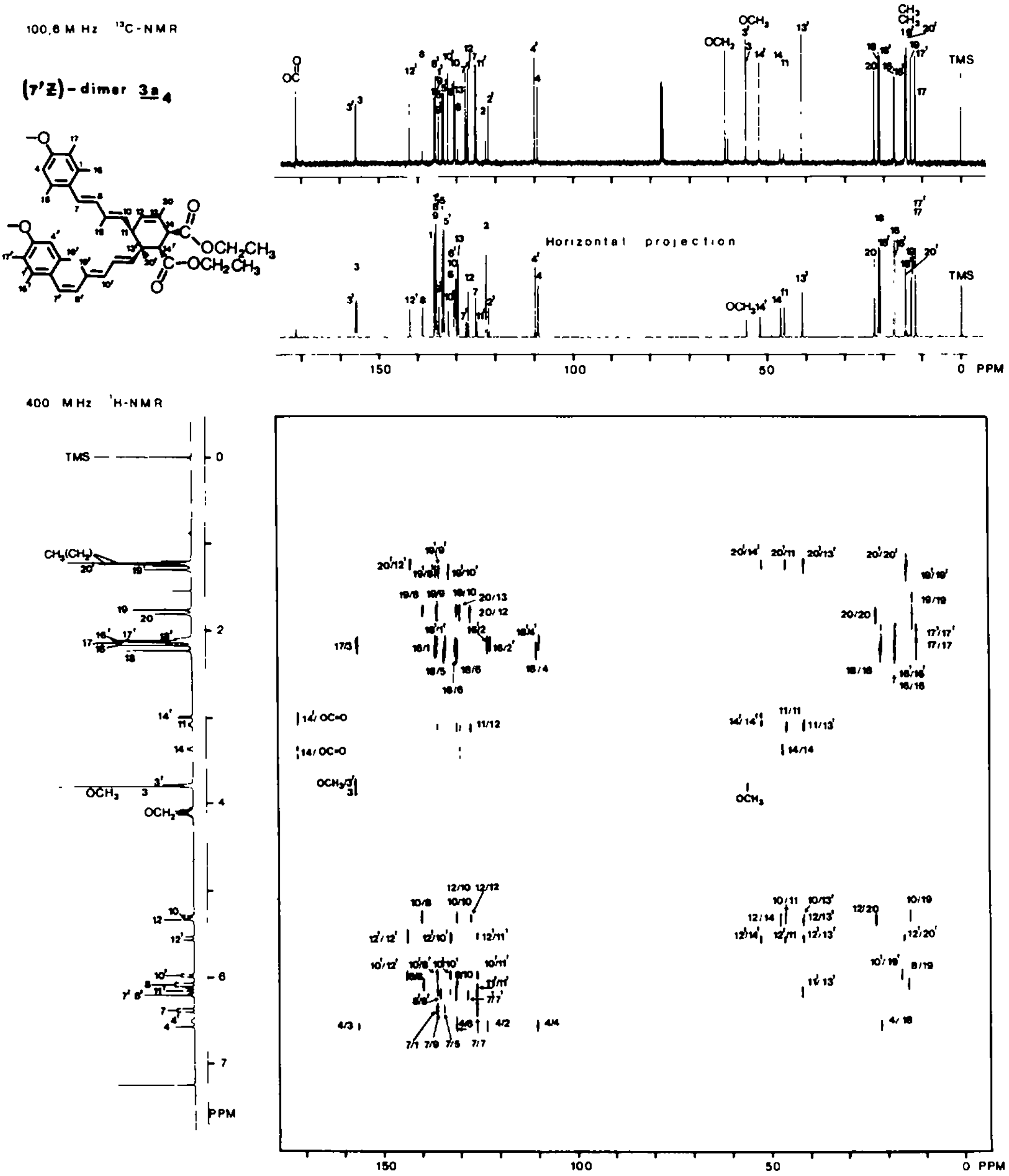


Figure 4. Top: 100.6 MHz ^{13}C-NMR and horizontal projection. Left: 400 MHz ^{1}H-NMR. Bottom: ^{1}H,^{13}C heteronuclear shift correlated 2D of 3a$_4$ optimized for long-range couplings J_{CH}~ 10 Hz (approx. 100 mg in 0.6 ml CDCl$_3$).

In a last step a series of NO experiments was performed in order to obtain additional information on the steric arrangement of the substituents on the cyclohexene. For comparison all these experiments were also performed for the dimers $\underline{2a}_1$ and $\underline{2a}_2$ the structures of which already had been elucidated by X-ray analyses. Further spectral reference data were also available from the previous NMR study on $\underline{1a}$ and on its different (Z)-isomers, including the assignment of the signals of the aromatic end groups[4].

As an example we briefly discuss the derivation by NMR of the structure of $\underline{3a}_4$. Fig. 3 shows the 400 MHz COSY-LR spectrum of $\underline{3a}_4$. On the top the 1D ^{1}H-spectrum and the assignments are presented. A number of broad signals are seen in the proton spectrum (H-4', 3'-MeO and the aromatic methyl protons of 18'-Me, 17'-Me, and 16'-Me). These broadenings together with the significant high-field shift of one of the in-chain methyl groups (19'-Me) from its normal position at 1.8-2 ppm to 1.3 ppm points to a (7'Z)-configuration with hindered rotation around the 6'-C, 7'-C single bond. The upfield shift of the 19'-Me signal is caused by the non-planar arrangement with protons of 19'-Me mainly above or below the benzene ring. Similar upfield shifts were previously reported for related monomeric (7Z)-isomers[4,8]. The (7'Z) configuration of $\underline{3a}_4$ is further supported by the observation of a coupling constant of $J_{7',8'} \sim 12.5$ Hz which is measured from the two very weak satellites on either side of the signal at 6.213 ppm. That the 7'-C,8'-C double bond possesses a (Z) configuration and not the 7-C,8-C double bond is unequivocally derived from the connectivities revealed in Fig. 3. Since most of the cross-peaks of the broadened signals are too small to be seen, it is advantageous to commence the deduction of the sequence of coupled protons at the sharp signal of H-4 at 6.58 ppm. From here relevant cross-peaks are detected with H-7, 4-MeO, 18-Me, 16-Me, and 17-Me. As expected the cross-peaks between H-4 and 17-Me in meta-position are slightly less intense than those to 16-Me and 18-Me in para and in ortho positon.

From H-7 connectivities are found to H-8 ($J_{7,8}$= 15.8 Hz, trans), H-10, 18-Me, 16-Me and weakly to 17-Me over up to 6 intervening bonds. From H-10 a strong cross-peak is detected with 19-Me. On the other hand, protons of 19'-Me at 1.296 ppm can be linked to H-12' (weak) and to H-10' (strong). With these and some further connectivities shown in Fig. 3 the full sequence of the coupled protons of $\underline{3a}_4$ and the (7'Z) configuration is firmly established.

It has been already mentioned above that the ^{1}H,^{13}C COSY is particularly useful for the deduction of structural information and for the confirmation of ^{1}H and ^{13}C assignments. In Fig. 4 the corresponding results for $\underline{3a}_4$ are presented.

This 2D spectrum contains a wealth of information as can be seen from the numerous cross-peaks connecting protons and carbons spin-coupled over 2 and 3 bonds. In addítition some of the one-bond connectivities already known from the one-bond experiment are also detectable. As in the homonuclear COSY some cross-peaks of broadened proton signals are too weak to be detected. Clearly visible e.g. are cross-peaks between H-4 and carbons 3, 6, 2, 4, and 18; between H-7 and 1-C, 9-C, 5-C and 7-C. Examples for the connectivity of protons and carbons of the cyclohexene ring are the cross-peaks of the 20'-Me protons with 12'-C (which is part of the longer side chain containing (7'Z)), with 14'-C, 11-C, 13'-C, and 20'-Me. Furthermore, H-11 gives cross-peaks with 12-C, 11-C, 13'-C, and in addition H-12' with 12'-C, 10'-C, 11'-C, 14'-C, 11-C, 13'-C, and 20'-Me. These examples sufficiently illustrate the reliability of the assignments of ^1H and ^{13}C signals when such 2D techniques are applied.

Further information on the sterochemistry of the cyclohexene rings was obtained from the values of some proton couplings and from NO difference experiments in comparison with the compounds $\underline{2a}_1$ and $\underline{2a}_2$ (see Tab. 2 and Exp.Part). Thus, in cyclohexene type 1 and 4 ($\underline{2a}_1$, $\underline{3a}_1$, and $\underline{3a}_4$) H-11 is quasi-axially oriented and the coupling $J_{11,12}$ is only about 1 Hz. The signal of 20-Me is additionally broadened by homoallylic coupling to H-11. In rings of type 2 and 3 ($\underline{2a}_2$, $\underline{2b}_2$, and $\underline{2b}_3$) H-11 is quasi-equatorially oriented. Hence, $J_{11,12}$ is about 5 Hz and the signal of 20-Me is sharper. The relative orientation of H-11 and 20'-Me is mainly reflected by the measured NO enhancements. Irradiation of 20'-Me in $\underline{3a}_4$ (Tab. 2) gives no significant NO enhancements at H-11, H-14, and H-14'. On the other hand in type 1, 2, and 3 medium NO enhancements (approx. 4-7.6%) were found between 20'-Me and H-11 in accordance with their cis relation. In type 2 a strong NO enhancement at H-14 of 8-12% was obtained upon irradiation of 20'-Me in agreement with their mutual 1,3-diaxial orientation. Additional information is provided by the coupling between H-14 and H-14', being 10.6 Hz in type 2 and 3 (diaxial) and approx. 7 Hz in type 1 and 4.

The stereochemistry of the substituents on the cyclohexene rings is also reflected by a comparison of their ^{13}C chemical shifts. Thus, $\underline{2a}_1$, $\underline{3a}_1$, and $\underline{2a}_2$, $\underline{2b}_2$, respectively, have closely related shifts of the ring carbons, e.g. 20'-Me (equatorial) at 23.4 ppm in the former pair and at 19 ppm (axial) in the latter pair (see Exp.Part).

Table 2. Relevant NO enhancements of $\underline{3a}_4$ (in %; 400 MHz)

Irradiation ppm	Proton	Observed NOE	Conclusions	
1.22	20'-Me $\underline{CH_3}CH_2$	H-11' 9.2, H-10 9.2, H-12' 3.1, H-14 ~1.0, H-11 ~0, H-14 ~1.3, OCH_2>0	<u>trans</u>:	20'-Me/H-11 20'-Me/H-14'
1.295	19'-Me	H-11' 10.0, H-14 ~1.5, H-10 ~1	(9E)	
1.759	19-Me	H-7 14.3, H-11 8.0, H-12 ~1	(7E,9E)	
1.805	20-Me	H-12 8.2, H-14 7.0		
2.998	H-14'	H-14 11.5, H-12' 4.3	<u>cis</u>:	H-14/H-14'
3.090	H-11	H-12 6.2, H-12' 4.7, H-14' 3.2, 19-Me 1.5		H-11/19-Me
3.374	H-14	H-14' 9.1		H-14/H-14'
5.534	H-12'	H-10' 5.3, H-14' 3.3, H-11 2.8		

In $\underline{2b}_3$ virtually the same shift of 20'-Me (23.98 ppm) was observed as in compounds characterized by the subscript 1 (Tab. 1). In $\underline{3a}_4$ the signal of 20'-Me is assigned at about 14 ppm. The corresponding upfield shift of ~5 ppm compared to compounds with the subscript 2 at 19 ppm is explained by the additional steric interaction with the 1,3-diaxial substituent R^6 at 14-C. For further spectroscopic data we refer to the Exp.Part.

DISCUSSION

Mode of the photosensitized [4+2]-dimerization in the aromatic retinoid series

A theoretical rationalization of the differences between thermal and photochemical cycloaddition reactions has been given by Woodward and Hoffmann[9]. Correlation diagrams for the molecular orbitals involved have been designed and then classified according to the symmetry elements of the (assumed) transition state. Such a model allows one to predict the selection rules for thermal and photochemical cycloadditions. On the basis of symmetry selection rules this simple picture correctly predicts that the synchronous thermal Diels-Alder reactions are allowed while synchronously proceeding photochemical [4+2]-cycloadditons are forbidden. On the other hand, photochemical cyclobutane formation is allowed while thermal [2+2]-cycloaddition is forbidden on the basis of these selection rules. The latter prediction is consistent with a large portion of known experimental data, but these are missing for the increasing number of photochemical [4+2]-cycloadditions. Thus, it is difficult to decide whether or not a photochemical [4+2]-cycloaddition proceeds synchronously.

A careful examination of Tab. 1 shows that the steric arrangements of the substituents on the cyclohexene ring photochemically formed exclude synchronous reactions. This fits into the above mentioned theoretical rationalization of the differences between thermal and photochemical cycloaddition reactions. Therefore, one has to assume a two step mechanism for the observed photochemical [4+2]-cyclodimerizations of aromatic retinoids. Furthermore, it is noteworthy that on all dimers (Tab. 1) the centre 14'-C bears a downward axial H and an equatorial COX, possibly indicating that the first bond is formed between 14'C of an electronically excited (all-E) or (7'Z) monomer and 14-C of a ground state (all-E) monomer. In the resulting biradicals rotational equilibrium can be established before the final ring closure occurs. This leads to various diastereomers, the number of which is limited by mutual steric hindrance of the substituents on the generated cyclohexene.

Competitive light absorption of sensitizer and substrate and its effect upon the photoreaction.

In the presence of hematoporphyrin 1a and 1b photodimerize, each giving a pair of (all-E)-dimers ($2a_1$, $2a_2$ and $2b_2$, $2b_3$, respectively). When the wavelengths of the incident light are extended to the UV, one (all-E) compound ($2a_1$) is formed again, however $2a_2$ is substituted by two (7'Z)-dimers $3a_1$ and $3a_4$. Steric as well as kinetic reasons might be responsible for the absence of any (7Z,7'Z)-dimers. Since the actual concentration of photochemically formed (7Z)-1a is much lower than that of the starting material (all-E)-1a the probability for the formation of (all-E)-dimers is correspondingly higher than for the formation of (7'Z)-dimers and almost zero for (7Z,7'Z)-dimers.

At the concentrations used (Exp. Part) the absorption of 1a dominates that of the sensitizer in the considered wavelengths region (Tab. 3). Therefore we assume the existence of an energy cascade from the substrate to the sensitizer and back to 1a, hereby attenuating the originally absorbed energy to the low lying hematoporphyrin triplet state. It is well known that the transfer of triplet energy decreases with increasing energy difference of the participating triplets. For this reason the absorption of the mercury emission line 366 nm with an energy of 78.1 kcal/einstein leads to an excited state of 1a from which (7Z)-isomerization can occur but evidently no energy transfer to the hematoporphyrin triplet with its energy of about 37.2 kcal/mol.

Table 3. Competitive absorption of the sensitizer hematoporphyrin and of the substrate 1a in ethanolic solution

2 kW Hg High Pressure Lamp			Sensitizer	Substrate 1a
λ nm	E_λ kcal einstein^{-1}	I_o einstein h^{-1}	$I_{abs.}^{a)}$ %	$I_{abs.}^{a)}$ %
436	65.5	0.35$^{b)}$	18.4	81.6
405/8	70.6/70.0	0.27$^{b)}$	27.8	72.2
366	78.1	0.65$^{c)}$	8.5	91.5

a)in percent of I_o calculated from eq. (1); b)cut-off filter A ($\lambda \geq 400$ nm); c)cut-off filter B ($\lambda \geq 365$ nm) (see Exp. Part).

EXPERIMENTAL PART

General remarks: M.ps. were measured on a Büchi SMP-20 in open capillaries. Mass spectra were recorded on a MS 9 from AEI, Manchester, updated with a ZAB console plus data system 3000. Only relevant signals are given in m/z (relative intensity in per cent referring to the basis signal = 100%). NMR spectra in $CDCl_3$, δ in ppm relative to TMS (= 0 ppm) as internal standard. Coupling constants J in Hz. ^{1}H-NMR spectra at 400 MHz and ^{13}C-NMR spectra at 100.6 MHz were recorded at approx. 23°C on a WM-400 Bruker Spectrospin FT-NMR spectrometer combined with an ASPECT 3000 computer with 320 K memory. DISNMR versions 1984 and 1985 were used. The multiplicities of the ^{13}C signals (qa quartet, t triplet, d doublet, s singlet) were obtained from ^{1}H-coupled spectra, by DEPT or directly from the ^{1}H, ^{13}C COSY.

All the 2D spectra were acquired in the absolute value mode using standard microprograms of the Bruker Software Library. The NO enhancements were obtained from difference experiments with pre-irradiation on- and off-resonance. The enhancements were calculated by comparison to a control spectrum with off-resonance irradiation only. The following typical experimental conditions for the COSY LR experiments (Fig. 3) were used: Spectral width in F_2 and F_1 3030 Hz, 2K. 400 data points, zero-filling in F_1 to 1K, 400 increments in t_1 of 330 µs, relaxation delay 2.5 s, extra-delay for enhancing long-range couplings of 0.1 s, sinebell windows in F_2 and F_1, acquisition time 0.34 s, 80 scans per experiment and 2 dummy scans, total acquisition time approx. 28 h.

The ^{1}H, ^{13}C COSY were performed with polarization transfer delays of 0.0036 and 0.0018 s for the one-band variant [J(C,H) ~140 Hz] and 0.06 and 0.03 s (or 0.05 and 0.025 s) for the long-range variant [J(C,H) ~8.3 or 10 Hz]. Typical experimental conditions as those of Fig. 4 for $3a_4$ were: Spectral width 18518 and 3334 Hz, 4K·256 data points, zero-filling in F_1 to 512, 256 experiments, relation delay 2 s, polarization transfer delays of 0.05 and 0.025 s, acquisition time 0.11 s, sine-bell windows in F_2 anf F_1, 64 scans per experiment and 1 dummy scan, total acquisition time approx. 10 h. The ^{1}J(C,H) experiments were normally acquired with one fourth of the number of scans.

For the competitive absorption of hematoporphyrin and 1a (Tab. 3) the molar decadic absorption coefficients ε_λ were determined using a Beckman Lambda 9 spectrophotometer. The incident radiant flux given by the manufacturer of the lamp was corrected by the absorption of the corresponding cut-off filters. The radiant flux $I_{o,\lambda}$ obtained in this way was expressed as 100% and the radiant flux absorbed by the two components i at the beginning of the photosensitized reaction was calculated using equation (1)^{10}, where c_i [mol·l^{-1}] are the concentrations and l [cm] is the absorbing path length.

$$I_{abs,i} = 100\,\frac{\varepsilon_i\, c_i}{\sum\limits_{n=1}^{m} \varepsilon_n c_n}\left(1-10^{-l\sum\limits_{n=1}^{m}\varepsilon_n c_n}\right)\% \qquad (1)$$

General procedure of irradiation: Irradiations were performed at 20-23°C using a 2 kW high pressure mercury lamp (TQ 2024 from Heraeus, Hanau, FRG.) placed into a double walled quartz immersion well which contained the liquid cut-off filter. By pumping the filter solution was circulated through an external heat exchanger and the immersion well was fitted in a pyrex reaction vessel equipped with condensor, Argon inlet tube, and with a second pump to press upwords the substrate and sensitizer containing solution, on this way causing its circulation along the lamp and through a further external heat exchanger. Filter A (1 cm) eliminated all light below 400 nm and consisted of 24.5 g $CuSO_4$ $5H_2O$, 5.3 g $Fe_2(SO_4)_3$ $5H_2O$, 1.8 g $FeSO_4$ 1-$2H_2O$, 38.5 ml conc. H_2SO_4 and 1015 ml distilled H_2O. Filter B (1 cm) eliminated all light below 365 nm and consisted of 32.1 g $CuSO_4$ $5H_2O$, 1.05 g $Fe_2(SO_4)_3$ $5H_2O$, 7.7 ml conc. H_2SO_4 and 993 ml distilled H_2O.

Photoreactions at $\lambda \geq 400$ nm: Diethyl-6α-[(all-E)-6-(4-methoxy-2,3,6-trimethylphenyl)-4-methyl-1,3,5-hexatrien-yl]-5α-[(all-E)-4-(4-methoxy-2,3,6-trimethylphenyl)-2-methyl-1,3-butadienyl]-3,6-dimethyl-3-cyclohexene-1α,2α-dicarboxylate $2a_1$
and
diethyl-6α-[(all-E)-6-(4-methoxy-2,3,6-trimethylphenyl)-4-methyl-1,3,5-hexatrienyl]-5α-[(all-E)-4-(4-methoxy-2,3,6-trimethylphenyl)-2-methyl-1,3-butadienyl]-3,6-dimethyl-3-cyclohexene-1β,2α-dicarboxylate $2a_2$.

A solution of 15 g (42.3 mmol) 1a and 0.75 g (1.25 mmol) hematoporphyrin in 2.5 l ethanol was irradiated for 1.5 hours using Filter A. Then 0.75 g hematoprophyrin were added again and the irradiation was continued for further 1.5 hours to give a total irradiation time of 3 hours. Analytical pure samples Of $2a_1$ and $2a_2$ were obtained by repeated CC on silica gel (1. cyclohexane-ether 8:2; 2. toluene-dichloromethane 8:2).

Dimer $2a_1$: Recrystallized from ethanol-light petrol ether 8.6 g (57%), m.p. 135-136°C. MS 708 (7,M^+), 355 (24), 354 (93), 339 (18), 281 (32), 228 (14), 204 (16), 203 (52), 191 (20), 163 (69), 150 (100), 29 (16). Anal.calc. for $C_{46}H_{60}O_6$ (708.98) C 77.93 H 8.53; found C 78.13 H 8.64. ^{1}H-NMR δ 1.200 and 1.271 (2t, J ~7.5, $2CH_2\underline{CH_3}$), 1.269 (s, 20'-Me), 1.822 (s, 20-Me), 1.910 (s, 19-Me), 1.962 (s, 19'-Me), 2.208 (s, 16'-Me), 2.212 (s, 16-Me), 2.128 (s, 17-Me), 2.136 (s, 17'-Me), 2.268 (s, 18-Me and 18'-Me), 2.981 (d, J=6.9, H-14'), 3.086 (ddq, J=10.5, J~2, J~2, H-11), 3.410 (d, J=6.9, H-14), 3.792 and 3.793 (2s, 2MeO), 4.053 and 4.155 (2q, $2\underline{C}H_2CH_3$), 5.333 (q?, J~1.5, H-12), 5.365 (d, J=10.5, H-10), 6.052 (d, J=11, H-10'), 6.102 (d, J=16.4, H-8), 6.114 (d, J=15, H-12'), 6.160 (d, J=16.4, H-8'), 6.457 (d, J=16.4, H-7'). 6.438 (d, J=16.4, H-7), 6.494 (dd, J=11, J=15, H-11'), 6.573 (s, H-4), 6.583 (s, H-4'). Relevant NOE results.
Irradiation of
20'-Me: H-11 5.8%, H-11' 9%, H-14' 4.4%, H-10 ~1.6%, H-14 ~0.
20-Me: H-12 6%, H-14 5%,
19-Me: H-11 5.3%, H-7 10.7%,
19'-Me: H-7' 10.5%, H-11' 2.5%,
H-11: H-12 7.4%, 19-Me 0.7%
H-14: H-14' 9%
H-14': H-14 11%.

^{13}C-NMR δ 11.84 (2qa, 17/17'-Me), 12.71 (qa, 19'-Me), 12.81 (qa, 19-Me), 13.94 and 14.19 (2qa, $2CH_2\underline{C}H_3$), 17.37 (2qa, 16/16'-Me), 21.36 and 21.39 (2qa, 18/18'-Me), 22.46 (qa, 20-Me), 23.39 (qa, 20'-Me), 40.69 (s, 13'-C), 47.39 (d, 14-C), 47.51 (d, 11-C), 53.61 (d, 14'-C), 55.40 (2qa, 2MeO), 60.04 and 60.96 (2t, $2\underline{CH_2}CH_3$), 109.85 (2d, 4/4'-C), 122.49 (2s, 2/2'-C), 125.09 (d, 7-C), 125.48 (d, 7'-C), 127.05 (d, 12-C), 128.12 (d, 11'-C), 130.25 (s, 6'-C), 130.30 (s, 13-C), 130.48 (s, 6-C), 131.61 (d, 10-C), 131.72 (d, 10'-C), 133.36 (s, 9'-C), 133.69 (s, 5-C), 133.76 (s, 5'-C), 134.89 (d, 12'-C), 135.29 (s, 9-C), 135.82 and 135.89 (2s, 1/1'-C), 138.81 (d, 8-C), 138.96 (d, 8'-C), 155.87 (2s, 3/3'-C), 170.96 and 171.34 (2s, 2 carbonyl-C).

X-ray analysis of $2a_1$[11].

Crystal data: Monoclinic, $P2_1/a$; a=17.805(4), b=20.910(4), c=12.568(2) A, β=106.51(2)°. Density D=1.13 $Mg \cdot m^{-3}$, Z=4; $\mu(Mo\text{-}K_\alpha)$=0.06 mm^{-1}, crystal size 0.22·0.37·0.39 mm^3, temperature 190°K, wavelength 0.71069 A, Theta min/Theta max: 0/25°, peak-background ratio 5:1, total data measured 8411 excluding standards, total data observed 3720, rejection criterion I>2.5·sigma(I), number of parameters 506. The data were collected on a Nicolet R3m four-circle diffractometer fitted with a graphite monochromator and LT1 cooling apparatus.

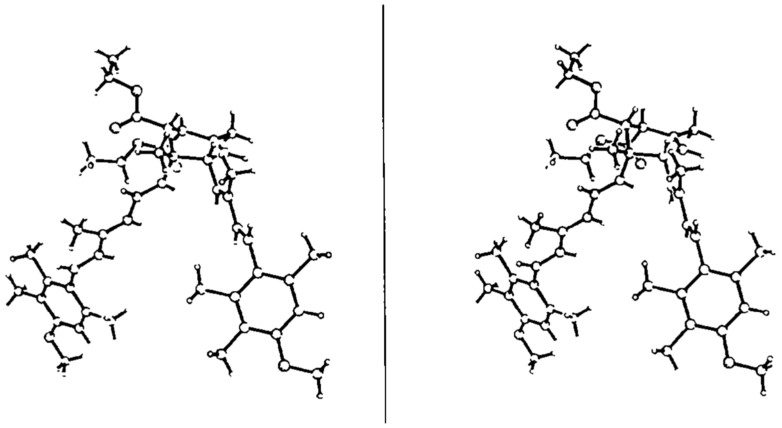


Figure 5. Stereoprojection of 2a$_1$.

Dimer 2a$_2$: Recrystallized from 2-propanone/ethanol 4.9 g (33.1%). m.p. 131-132°C. MS 708 (7, M+), 365 (24), 354 (93), 339 (18), 281 (32), 228 (14). 204 (16), 203 (52). 191 (20), 163 (69), 150 (100), 29 (16). Anal.calc. for $C_{46}H_{60}O_6$ (708.98), C 77.93 H 8.53; found C 78.19, H 8.63. ^{1}H-NMR δ 1.146 and 1.249 (2t, J~7.5, 2CH_2CH_3), 1.276 (s, 20'-Me), 1.736 (s, 20-Me), 1.837 (d?, 19-Me), 1.976 (d?, 19'-Me), 2.215 (s, 16'-Me), 2.226 (s, 16-Me), 2.137 (s, 17'-Me), 2.141 (s, 17-Me), 2.272 (s, 18'-Me), 2.286 (s,18-Me), 2.925 (dd, J=5.5, J=10, H-11), 3.135 (d, J=10.6, H-14'), 3.418 (d, J=10.6, H-14), 3.803 and 3.807 (2s, 2MeO), 4-4.2 (m, 2CH_2CH_3), 5.396 (d, J=10, H-10), 5.475 (d, J=5.5, H-12), 5.823 (d, J=15, H-12'), 5.983 (d, J=11, H-10'), 6.143 (d, J=16, H-8'), 6.182 (d, J=16, H-8), 6.402 (dd, J=11, J=15, H-11'), 6.445 (d, J=16, H-7), 6.507 (d, J=16, H-7'), 6.585 (2s, H-4/4'). Relevant NOE results. Irradiation of

20'-Me: H-11 7%, H-14 12%, H-11' 10%, H-14' ~0
20-Me: H-12 7%, H-14 5%
19-Me: H-11 6.5%, H-7 12%
19'-Me: H-7' 12%, H-11' 6.5%
H-11: H-12 8%, H-12' 2%, 19-Me 2.6%, H-10 2.2%
H-14: 20-Me ~1%
H-14': H-10 9.2%, H-12 4.8%
H-12': H-14' 4.8%, H-11 1.3%.

^{13}C-NMR δ 11.84 (2qa, 17/17'-Me), 12.66 (qa, 19'-Me), 12.95 (qa, 19-Me), 14.19 (2qa, 2CH_2CH_3), 17.37 and 17.40 (2qa, 16/16'-Me), 19.18 (qa, 20'-Me), 21.34 (2qa, 18/18'-Me), 21.41 (qa, 20-Me), 40.89 (s, 13'-C), 46.76 (d, 11-C), 47.87 (d, 14-C), 48.11 (d, 14'-C), 55.45 (2qa, 2MeO), 60.31 and 60.89 (2t, 2CH_2CH_3), 109.95 (2d, 4/4'-C), 122.53 and 122.62 (2s, 2/2'-C), 124.87 (d, 11'-C), 125.66 (d, 7-C), 126.14 (2d, 7'/12-C), 127.91 (s, 13-C), 130.18 and 130.28 (2s, 6/6'-C), 130.01 (d, 10-C), 131.51 (d, 10'-C), 133.72 (2s, 5/5'-C), 134.12 (s, 9'-C), 135.21 (s, 9-C), 135.78 (1/1'-C), 138.41 (d, 8-C), 138.60 (d, 8'-C), 140.44 (d, 12'-C), 155.94 and 156.00 (2s, 3/3'-C), 172.74 and 172.96 (2s, 2 carbonyl-C).

X-ray analysis of 2a$_2$[10].

Crystal Data: Triclinc P1. a=8.200(2), b=8.385(2), c=31.049 A, α=89.90, β= 93.47(2), γ=105.54(2)°. Density D=1.14 Mg·m^{-3}, Z=2; μ(Cu-K$_\alpha$)=0.55 mm^{-1}, crystal size 0.41·0.17·0.13 mm^3, temperature 293°K, wavelength 1.5418 A, Theta min/ Theta max: 0/55.75°, peak-background ratio 5:1, total data measured, 5668 excluding standards, total data observed 2518, rejection criterion I>2.5·sigma(I), number of parameters 469. The data were collected as described above but without using a cooling apparatus.

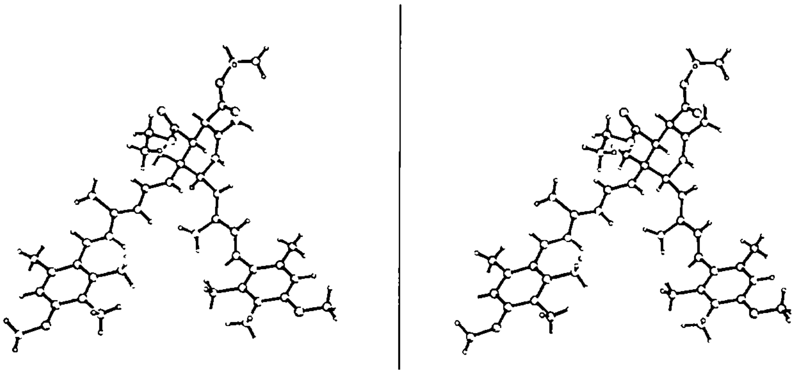


Figure 6. Stereoprojection of $2a_2$.

N,N'-Diethyl-6α-[(all-E)-6-(4-methoxy-2,3,6-trimethylphenyl)-4-methyl-1,3,5-hexatrienyl]-5α-[(all-E)-4-(4-methoxy-2,3,6-trimethylphenyl)-2-methyl-1,3-butadienyl]-3,6-dimethyl-3-cyclohexene-1β,2α-dicarboxamide $2b_2$
and
N,N'-diethyl-6α-[(all-E)-6-(4-methoxy-2,3,6-trimethylphenyl)-4-methyl-1,3,5-hexatrienyl]-5β-[(all-E)-4-(4-methoxy-2,3,6-trimethylphenyl)-2-methyl-1,3-butadienyl]-3,6-dimethyl-3-cyclohexene-1β,2α-dicarboxamide $2b_3$
A solution of 10 g 1b (28.3 mmol) and 0.75 g (1.25 mmol) hematoporphyrin in 2.5 l ethanol was irradiated for 3 hours using filter A. Then additional 0.75 g hematoporphyrin were added and the irradiation was continued for further 3 hours to give a total irradiation time of 6 hours. Analytical pure samples were obtained by repeated CC on silica gel (toluene-ethyl acetate-dichloromethane 1:3:6).

Dimer $2b_2$: Recrystallized from 2-propanone 2.5 g (25%)^{11}, m.p. 222-225°C (decomp.). MS 707 (3, M^+), 392 (34), 354 (12), 353 (50), 281 (37), 203 (26), 190 (28), 164 (15), 163 (100), 150 (81), 113 (15), 98 (19), 91 (17), 72 (19), 45 (13), 44 (24), 29 (28). Anal.calc. for $C_{46}H_{62}N_2O_4$ (707.01) C 78.15 H 8.84 N 3.96; found C 78.25 H 8.75 N 3.89. ^{1}H-NMR δ (the chemical shifts depend strongly on the concentration of $2b_2$) 0.934 and 1.071 (2t, J=7.5, $2CH_2\underline{CH_3}$), 1.301 (~s, 20'-Me), 1.707 (s, 20-Me), 1.833 (d, J=0.7, 19-Me), 1.968 (d, J~0.5, 19'-Me), 2.128 (s, 17-Me), 2.144 (s, 17'-Me), 2.204 (s, 16-Me), 2.224 (s, 16'-Me), 2.260 (s, 18-Me), 2.294 (s, 18'-Me), 2.868 (dd, J=6, J=10, H-11), 2.812 (d, J=10.5, H-14'), 3.150 and 3.280 ($2ABX_3$, $2NH\underline{CH_2}CH_3$), 3.260 (d, J=10.5, H-14), 3.788 and 3.808 (2s, 2MeO), 5.444 (d, J=6, H-12), 5.450 (d, J~10, H-10), 5.976 (d, J=10.5, H-10'), 5.989 (d, J=15, H-12'), 6.124 (d, J=16.5, H-8'), 6.156 (d, J=16.5, H-8), 6.418 (d, J=16.5, H-7), 6.434 (dd, J=10.5, J=15, H-11'), 6.502 (d, J=16.5, H-7'), 6.548 (s, H-4'), 6.582 (s, H-4), 6.69 (~t, 2NH).Relevant NOE results. Irradiation of
20'-Me: H-11 7.6%, H-14 7.6%, H-11' 8.7%
20-Me: H-12 and H-10, each approx. 3.1%
19-Me: H-7 11.1%, H-11 6.5%
19'-Me: H-7' 7.6%, H-11' 5.4%
16-Me: H-7 5%, H-8 ~3%, 17-Me ~1.5%.
^{13}C-NMR δ 11.83 (qa, 17'-Me), 11.89 (qa, 17-Me), 12.60 (qa, 19'Me), 12.86 (qa, 19-Me), 14.48 and 14.65 (2qa, $2CH_2\underline{C}H_3$), 17.32 (qa, 16'-Me), 17.39 (qa, 16-Me), 19.00 (qa, 20'-Me), 20.92 (qa, 20-Me), 21.32 (qa, 18'-Me), 21.49 (qa, 18-Me), 34.09 and 34.50 (2t, $2\underline{C}H_2CH_3$), 40.88 (s, 13'-C), 47.26 (d, 11-C), 48.60 (d, 14'-C), 48.62 (d, 14-C), 55.40 and 55.43 (2qa, 2MeO), 109.87 (2d, 4/4'-C), 122.31 (s, 2-C), 122.54 (s, 2'-C), 124.84 (d, 11'-C), 125.34 (d, 7-C), 125.41 (d, 12-C), 127.85 (d, 7'-C), 129.44 (s, 13-C), 130.09 (s, 6-C), 130.20 (s, 6'-C), 131.20 (d, 10-C), 131.26 (d, 10'-C), 133.67 (2s, 5'/9'-C), 133.72 (s, 5-C), 134.33 (s, 9-C), 135.76 (2s, 1/1'-C), 138.37 (d, 8-C), 138.55 (d, 8'-C), 141.40 (d, 12'-C), 155.72 (s, 3-C), 155.88 (s, 3'-C), 172.25 and 172.95 (2s, 2 carbonyl-C).
and
Dimer $2b_3$: Recrystallized from ether-light petrol ether 1.5 g (15%)^{12}, m.p. 215-216°C (decomp.). MS 707 (5, M^+), 706 (8), 393 (13), 392 (46), 354 (16), 353 (64), 282 (13), 281 (40), 204 (23), 203 (27), 190 (31), 164 (14), 163 (100), 150 (88), 113 (16), 98 (17), 91 (11), 69 (13), 44 (13), 43 (16), 41 (15). Anal.calc. for $C_{46}H_{62}N_2O_4$ (707.01) C 78.15 H 8.84 N 3.96; found C 77.92 H 8.70 N 3.92. ^{1}H-NMR δ 1.064 (s, 20'-Me), 1.077 and 1.082 (2t, J~7.5, $2CH_2\underline{CH_3}$), 1.679 (~s, 20-Me), 1.954 (d, J=1, 19-Me), 2.014 (d, J=1, 19'-Me), 2.152 (2s, 17/17'-Me), 2.219 (s,

16'-Me), 2.242 (s, 16-Me), 2.276 (s, 18'-Me), 2.307 (s, 18-Me), 2.698 (d, J=10.8, H-14'), 3.144 (d, J~10.8, H-14), 3.097-3.297 (m, $2NH\underline{CH_2}CH_3$) included 3.159 (dd, J=5.5, J=10.5, H-11), 3.813 and 3.816 (2s, 2MeO), 5.396 (d, J=10.5, H-10), 5.467 (d, J=5.5, H-12), 5.772 and 5.911 (2t, J~11, 2NH), 6.134 (d, J=10.5, H-10'), 6.170 (d, J~16, H-8'), 6.190 (d, J=16, H-8), 6.209 (d, J=15, H-12'), 6.465 (dd, J=5.5, J=10.5, H-11'), 6.471 (d, J=16, H-7), 6.511 (d, J=16, H-7'), 6.599 (s, H-4/4').

Relevant NOE results. Irradiation of

20'-Me: H-11' 5.8%, H-12' 3.1%, H-10 2.9%, H-11 3.4%, H-14' 3.6%

20-Me: H-12 6%, H-14 3%

19-Me: H-7 5%, H-11 5.5%

19'-Me: H-7' 5.5%, H-11' 7.7%

H-14': H-10 4.8%, NH(5.72 ppm) 3.8%

H-10: H-8 6.5%, H-14' 5%.

^{13}C-NMR δ 11.86 and 11.87 (2qa, 17/17'-Me), 12.78 (qa, 19'-Me), 12.89 (qa, 19-Me), 14.65 (2qa, $2CH_2\underline{C}H_3$), 17.39 and 17.41 (2qa, 16/16'-Me), 20.97 (qa, 20-Me), 23.98 (qa, 20'-Me), 21.37 (qa, 18'-Me), 21.47 (qa, 18-Me), 34.25 and 34.47 (2t, $2\underline{C}H_2CH_3$), 40.38 (s, 13'-C), 45.44 (d, 11-C), 49.83 (d, 14-C), 50.54 (d, 14'-C), 55.48 and 55.50 (2qa, 2MeO), 109.92 (d, 4/4'-C), 122.42 (and 122.59 (2s, 2/2'-C), 124.11 (d, 11'-C), 125.57 125.59 (2d, 7/7'-C), 125.76 (d, 12-C), 130.02 (s, 6-C), 130.13 (s, 13-C), 130.47 (s, 6'-C), 131.20 (d, 10-C), 131.69 (d, 10'-C), 133.59 (s, 5/5'-C), 133.75 (s, 9'-C), 134.32 (s, 9-C), 135.83 (s, 1/1'-C), 138.41 (d, 8-C), 138.82 (d, 8'-C), 140.32 (d, 12'-C), 155.84 (s, 3'-C), 155.94 (s, 3-C), 172.10 and 172.95 (2s, 2 carbonyl-C).

Photoreaction at λ ≳ 365 nm: Dimer $2a_1$
and
diethyl-6α-[(1E,3E,5Z)-6-(6-methoxy-2,3,6-trimethylphenyl)-4-methyl-1,3,5-hexatrienyl]-5α-[(all-E)-4-(4-methoxy-2,3-6-trimethylphenyl)-2-methyl-1,3-butadienyl]-3,6-dimethyl-3-cyclohexene-1β,2β-dicarboxylate $3a_1$,
and
diethyl-6β-[(1E,3E,5Z)-6-(4-methoxy-2,3,6-trimethylphenyl)-4-methyl-1,3,5-hexatrienyl]-5α-[(all-E)-4-(4-methoxy-2,3,6-trimethylphenyl)-2-methyl-1,3-butadienyl]-3,6-dimethyl-3-cyclohexene-1α,2α-dicarboxylate $3a_2$.

The procedure was analogous to the formation of $2a_1$ and $2a_2$, but for the irradiation filter B was used and the repeated CC was performed using cyclohexane-ether 8:2, then 9:1 and finally neat toluene. The amount of starting material 1a was 15 g.

Dimer $2a_1$: 8.5 g (56.6%); data are given above.

Dimer $3a_1$: Recrystallized from acetonitrile-trichloromethane 3 g (20.2%), m.p. 151-152°C. MS 708 (3, M^+), 355 (25), 354 (100), 339 (18), 281 (34), 251 (12), 228 (9), 204 (17), 203 (54), 191 (21), 163 (66), 150 (93), 131 (14), 29 (17). Anal.calc. for $C_{46}H_{60}O_6$ (708.98) C 77.93 H 8.53; found C 78.11 H 8.62. ^1H-NMR δ 1.204 (t, s included, J=14, $CH_2\underline{CH_3}$ and 20'-Me), 1.238 (t, J=14, $CH_2\underline{CH_3}$), 1.292 (d, J~1, 19'-Me), 1.827 (s br, 20-Me), 1.887 (d, J=1.1, 19-Me), 2.111 (s, 18'-Me), 2.126 (s br, 17'-Me), 2.138 (s, 17-Me), 2.146 (s br, 16'-Me), 2.201 (s, 16-Me), 2.258 (s, 18-Me), 2.955 (d, J=7, H-14'), 3.056 (dqa?, H-11), 3.391 (dm, J=7, H-14), 3.790 and 3.804 (2s, 2MeO), 4.102 and 4.056 (2m, $2\underline{CH_2}CH_3$), 5.314 (d, J=10.3, H-10), 5.326 (d?, H-12), 6.051 (d, J=11, H-10'), 6.065 (d, J=15.2, H-12'), 6.086 (d, J=16.4, H-8), 6.164 (d, J=12.4, H-7'), 6.219 (d, J=12.4, H-8'), 6.325 (dd J~11, J=15.2, H-11'), 6.421 (d, J=16.4, H-7), 6.523 (s, H-4'), 6.580 (s, H-4). Relevant NOE results. Irradiation of

20'Me: H-11' 7.6%, H-11 4.1%, H-14' 3.3%, H-12' ~1.4%, H-10' ~0.6%

20-Me: H-12 4.3%, H-14 3%

19-Me: H-7 6.9%, H-11 ~2%, H-12 ~1.6%

19'-Me: H-11' 4.0%

H-14: H-14' 7.6%

H-14': H-14 9.2%, H-11 3%

H-11: H-14' 4%, H-19 1.7%, H-12 and H-10 ~1.3%.

^{13}C-NMR δ 11.73 (qa, 17'-Me), 11.85 (qa, 17-Me), 12.80 (qa, 19-Me), 13.96 (qa, 19'-Me), 14.13 and 14.27 (2qa, $2CH_2\underline{C}H_3$), 17.26 (qa, 16'-Me), 17.39 (qa, 16-Me), 21.02 (qa, 18'-Me), 21.36 (qa, 18-Me), 22.47 (qa, 20-Me), 23.40 (qa, 20'-Me), 40.64 (s, 13'-C), 47.34 (d, 14-C), 47.56 (d, 11-C), 53.69 (d, 14'C), 55.44 and 55.69 (2qa, 2MeO), 60.03 and 60.95 (2t, $2\underline{C}H_2CH_3$), 109.08 (d, 4'-C), 55.44 and 55.69 (2qa, 2MeO), 60.03 and 60.95 (2t, $\underline{C}H_2CH_3$), 109.08 (d, 4'-C), 109.91 (d, 4-C), 121.72 (s, 2'-C), 122.53 (s, 2-C), 125.03 (d, 7-C), 127.05 (d, 12-C), 127.15 (d, 7'-C), 127.88 (d, 11'-C), 130.27 (s, 6-C), 130.35 (s, 13-C), 131.01 (s, 6'-C), 131.56 (d, 10-C), 133.31 (d, 10'-C), 133.43 (s, 5'-C), 133.75 (s, 5-C), 134.24 (s, 9'-C), 135.04 (d, 12'-C), 135.27 (s, 9-C), 135.48 (s, 1'-C), 135.82 (s, 1-C), 135.88 (s, 3-C and d, 8'C), 136.05 (s, 3'-C), 138.79 (d, 8-C), 171.01 and 171,34 (2s, 2 carbonyl-C).

Dimer $\underline{3a}_4$: Recrystallized from light petrol ether-trichloromethane 2.8 g (18.9%), m.p. 146-148°C. MS 708 (2, M^+), 355 (23), 354 (89), 339 (18), 281 (35), 251 (15), 204 (16), 203 (54), 191 (22), 163 (61), 150 (100), 131 (15), 29 (19). Anal.calc. for $C_{46}H_{60}O_6$ (708.98) C 77.93 H 8.53; found C 78.03 H 8.58. ^{1}H-NMR δ 1.219 (t, s included, $CH_2\underline{CH}_3$ and 20'-Me), 1.235 (t, J~6.7, $CH_2\underline{CH}_3$), 1.296 (s br, 19'-Me), 1.759 (d, J=1.2, 19-Me), 1.805 (sext. 20-Me), 2.11 (s br, 18'-Me), 2.123 (s, 17-Me), 2.135 (s, 17'-Me), 2.143 (s, 16'-Me), 2.177 (s, 16-Me), 2.238 (s, 18-Me), 2.997 (d, H-14'), 3.090 (d sext, J=10.5, 5J=1-2, H-11), 3.375 (d, J=7, H-14), 3.785 and 3.804 (2s, 2MeO), 4.04-4.16 (m, $2\underline{CH}_2CH_3$), 5.311 (d, J=10.5, H-10), 5.340 (d?, H-12), 5.554 (d, J=15.2, H-12'), 5.986 (d, J=11.3, H-10'), 6.090 (d, J=16.2, H-8), 6.159 (dd, J=11.0, J=15.5, H-11'), 6.213 (~s, H-7', H-8'), 6.389 (d, J=15.8, H-7), 6.516 (s br, H-4'), 6.579 (s, H-4). The NOE results for $\underline{3a}_4$ are given in Tab. 2.
^{13}C-NMR δ 11.72 (qa, 17'-Me), 11.83 (qa, 17-Me), 12.93 (qa, 19-Me), 13.96 and 14.18 (2qa, $2CH_2\underline{C}H_3$), 14.40 (qa, 19'-Me), 14.44 (qa, 20'-Me), 17.15 (qa, 16'-Me), 17.34 (qa, 16-Me), 20.94 (qa, 18'-Me), 21.32 (qa, 18-Me), 22.39 (qa, 20-Me), 41.11 (s, 13'-C), 45.74 (d, 11-C), 46.70 (d, 14-C), 51.98 (d, 14'-C), 55.40 and 55.47 (2qa, 2MeO), 60.09 and 60.79 (2t, $2\underline{C}H_2CH_3$), 109.14 (d, 4'-C), 109.88 (d, 4-C), 121.81 (s, 2-C), 122.49 (s, 2'-C), 124.87 (d, 11'-C), 125.22 (d, 7-C), 127.07 (d, 12-C), 127.65 (d, 7'-C), 129.68 (s, 13'-C), 130.30 (s, 6-C), 130.51 (d, 10-C), 130.71 (s, 6'-C), 132.20 (d, 10'-C), 133.32 (s, 5'-C), 133.69 (s, 5-C), 134.68 (s, 9'-C), 135.35 (s, 9-C), 135.39 (s, 1'-C), 135.48 (d, 8'-C), 135.78 (s, 1-C), 138.84 (d, 8-C), 142.14 (d, 12'-C), 155.89 (s, 3-C), 156.13 (s, 3'-C), 171.32 and 171.40 (2s, 2 carbonyl-C).

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REFERENCES AND NOTES

1. Presented in part by K.-H. P. in 1985 at the Symposium on Organic Photochemistry in Sendai, at the XIIth International Conference on Photochemistry in Tokyo, and at the 9th Meeting of the Photochemistry Section in the Society of German Chemists (GDCh) in Siegen.
2. For an introductory review see H. Mayer, W. Bollag, and R. Rüegg, Experientia 34, 1105 (1978).
3. K.-H. Pfoertner, G. Englert, and P. Schönholzer, Tetrahedron 43, 1321 (1987).
4. G. Englert, S. Weber, and M. Klaus, Helv.Chim.Acta 61, 2697 (1978).
5. K. Tsukida and M. Ito, J.Nutr.Sci.Vitaminol. 26, 319 (1980).
6. M. Mousseron-Canet, J.-C. Mani, C. Favie, and D. Lerner, C.R. Hebd. Séances Acad.Sci.Ser. C, 153 (1966).
7. M. Mousseron-Canet, J.-C. Mani, and D. Lerner, Bull.Soc.Chim. Fr., 3043 (1966).
8. S. Herzberg, G. Englert, P. Bergquist, and S. Liaaen-Jensen, Bull.Soc.Chim. Belg. 95, 801 (1986).
9. R.B. Woodward, and R. Hoffmann, Angew.Chem., Int.Ed.Engl. 8, 781 (1969).
10. K.-H. Pfoertner in "Photochemistry in Organic Synthesis" (Ed. J.D. Coyle), Special Publication No. 57. The Royal Society of Chemistry, London 1986, p. 260.
11. The refinement has been performed using the SHELXTL package of the R3m system: G.M. Sheldrick, University of Goettingen, FRG, SHELXTL 3.0, 1981. Coordinates and thermal parameters have been deposited at the Cambridge Crystallographic Data Centre.
12. The low yields of $\underline{2b}_2$ and $\underline{2b}_3$ do not reflect a less effective dimerization, but they are due to the inferior stability of aromatic retinoid dimers with ethyl amide groups, which give rise to considerable losses during the work-up of the reaction mixtures.