234. Intramolecular [2 + 2]-Photocycloadditions of 6-Allyl-2-cyclohexenones. Formation of Tricyclo[3.3.1.$0^{2,7}$]nonan-6-ones and Tricyclo[4.2.1.$0^{3,8}$]nonan-7-ones

by **Wolfgang Fröstl** and **Paul Margaretha**

Département de Chimie Organique, Université de Genève
30, quai Ernest Ansermet, CH–1211 Geneva 4, Switzerland

(10. VI. 76)

Summary. Alkylation of 4,4,6-trimethyl-2-cyclohexenone (**1**) in toluene in the presence of sodium bis(trimethylsilyl)amide proceeds smoothly to give high yields of compounds **2**. Irradiation (λ = 366 nm) of the 6-allyl-4,4,6-trimethyl-2-cyclohexenones **2a–c** yields mixtures of the isomeric tricyclo-nonanones **3** and **4**, the product ratio depending on the substituent R′ of the allylic side chain and on the solvent. The quantum yields for the cyclizations are given.

Some examples of intramolecular [2 + 2]-photocycloadditions of cyclic α,β-unsaturated ketones to olefins have been reported in the literature. The olefinic double bond can be either located in a side chain, *e.g.*, in the classical carvone – carvone-camphor interconversion [1] [2], in the analogous cyclization of isopiperitone [3] and in the addition of a ketene moiety to a cyclohexenone [4], or it can be located in a common, medium sized ring as in the photoreaction of a 2,7-cyclodecadienone [5].

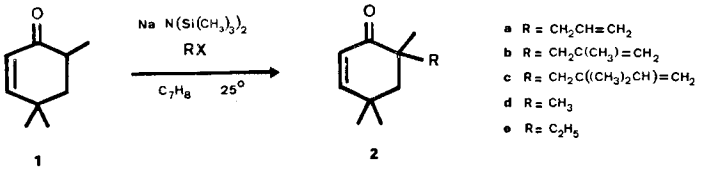
One common aspect of all these reactions is the exclusive formation of only one photoproduct. This contrasts with the results obtained in intermolecular photoadditions of cyclic enones to olefins: as not only the orientation of the addition, the stereochemistry of the ring-fusion and the relative arrangement of the substituents on the four-membered ring formed [6] [7], but even the reactive double bond (C=C or C=O) of the enone system [8] [9] are variables, usually more than one photoadduct is formed in these reactions.

We now report results on the intramolecular [2 + 2]-photocycloadditions of the 6-allyl-2-cyclohexenones **2a–c.**

Up to now 4,4-disubstituted 2-cyclohexenones with alkyl substituents on C(6) had only been obtained in poor yields. 6,6-Dibenzyl-4,4-dimethyl-2-cyclohexenone, *e.g.*, was prepared from 4,4-dimethyl-2-cyclohexenone, sodium pentanolate and benzyl chloride in 20% yield [10], and 4,4,6,6-tetramethyl-2-cyclohexenone (**2d**) from either the same starting material or from 4,4,6-trimethyl-2-cyclohexenone (**1**), sodium amide and methyl iodide in 18% [11] resp. 45% yield [12], or by a multistep synthesis (hydroboration of the enamine of 3,3,5,5-tetramethylcyclohexanone, followed by thermolysis of the aminoalcohol and oxidation of the 2-cyclohexenol) in 20% overall yield [13].

We have developed a convenient method for the synthesis of compounds **2** starting from **1** and using sodium bis(trimethylsilyl)amide [14] as a base (*Scheme 1*). Our method allows working in a homogeneous medium and gives pure products in good yields. Sodium bis(trimethylsilyl)amide has already been employed in the metalation of esters, nitriles and haloesters [15–17]. The spectroscopic data of compounds **2** are summarized in Table 1.

Scheme 1



1 2

Table 1. *Yields and Physical Data for Compounds* **2**

Compound	Yield	b.p.	UV.[a])	NMR.[b])
2a	82%[c])	72–74° /0.5 Torr	222 nm (12000) 343 nm (34)	6.42 (*d* × *d*, 1H, *J* = 1 and 10 Hz), 5.65 (*d*, 1H, *J* = 10 Hz), 5.60 (*m*, 1H), 5.08 (*m*, 1H), 4.80 (*m*, 1H), 2.22 (*ABX*, 2H), 1.73 (*AB*, 2H), 1.15 (*s*, 6H), 1.07 (*s*, 3H)
2b	75%[c])	78–82° /0.5 Torr	222 nm (12200) 343 nm (40)	6.55 (*d* × *d*, 1H, *J* = 1 and 10 Hz), 5.80 (*d*, 1H, *J* = 10 Hz), 4.80 (*m*, 1H), 4.65 (*m*, 1H), 2.40 (*AB*, 2H), 1.75 (*AB*, 2H), 1.60 (*s*, 3H), 1.20 (*s*, 6H), 1.17 (*s*, 3H)
2c	60%[d])	95–98° /0.5 Torr	222 nm (12100) 343 nm (58)	6.45 (*d* × *d*, 1H, *J* = 1 and 10 Hz), 5.72 (*d*, 1H, *J* = 10 Hz), 4.80 (*m*, 2H), 4.59 (*m*, 1H), 2.33 (*AB*, 2H), 1.95 (*m*, 1H), 1.75 (*AB*, 2H), 0.90–1.20 ($5CH_3$, 15H)
2d	81%[c])	*cf.* [13]	220 nm (16000) 342 nm (54)	*cf.* [18]
2e	63%[c])	110–112° /12 Torr	221 nm (15000) 342 nm (37)	6.45 (*d*, 1H, *J* = 10 Hz), 5.68 (*d*, 1H, *J* = 10 Hz), 1.70 (*AB*, 2H), 1.60 (*q*, 2H), 1.20 (*s*, 6H), 1.05 (*s*, 3H), 0.83 (*t*, 3H, *J* = 7 Hz)

[a]) In cyclohexane. [b]) In CCl_4. [c]) From alkyl iodide. [d]) From alkyl bromide.

Irradiation (λ = 366 nm) of **2a–c** in either cyclohexane or acetonitrile leads to the concurrent formation of the tricyclo[3.3.1.$0^{2,7}$]nonan-6-ones **3** and the tricyclo-[4.2.1.$0^{3,8}$]nonan-7-ones **4** (*Scheme 2*). Compounds **3** and **4** are isomers. Their formation differs only in the orientation of the addition of the olefinic double bond to the C=C bond of the enone system. No oxetane formation was observed. Product distributions and quantum yields for the disappearance of starting material are given in Table 2. The spectroscopic data on the basis of which the structures of **3** and **4** were assigned[1]) are summarized in Table 3.

[1]) From NMR. and MS. data compounds **4** could also be tricyclo[4.2.1.$0^{3,7}$]nonan-8-ones, formed *via* trapping of a hypothetical 1,3-diradical, intermediate of a lumiketone rearrangement, by the olefinic double bond. Apart from the fact that this possibility represents a highly improbable reaction mechanism – it has been shown that such lumiketone rearrangements proceed in a concerted-like fashion [19] –, the IR. spectra clearly exclude such a structure, as bicyclo[2.2.1]heptan-7-ones and their derivatives exhibit carbonyl absorption at 1783 cm^{-1} [20], *i.e.* at much higher wavenumbers than those observed for compounds **4**.

Scheme 2

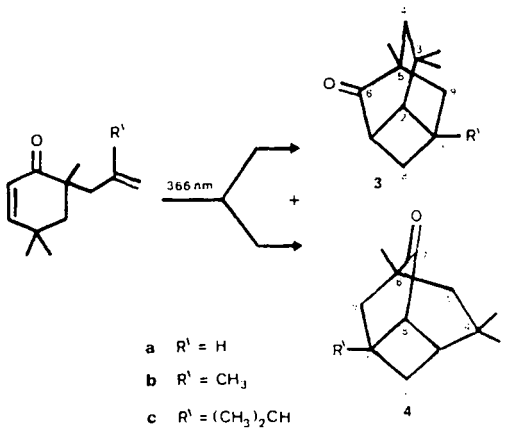


Table 2. *Product Distribution* **3**:**4** *as a Function of the Solvent, and Quantum Yields for the Irradiation* (λ = *366 nm*) *of Ar-degassed Solutions of* **2a–c** *in Cyclohexane at Room Temperature* (Average Error: +7%)

	solvent	**2a**	**2b**	**2c**
3:**4**	CH_3CN	100:0	79:21	67:33
	C_6H_{12}	100:0	71:29	58:42
ϕ-2	C_6H_{12}	0.19	0.14	0.20

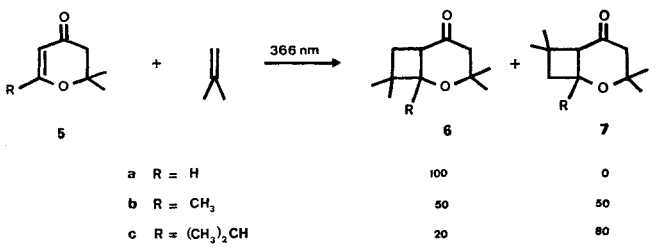
Table 3. *Spectroscopic Data for Photoproducts* **3** *and* **4**

	3a	**3b**	**3c**	**4b**	**4c**
IR.[a]	1722 cm^{-1}	1723 cm^{-1}	1725 cm^{-1}	1740 cm^{-1}	1743 cm^{-1}
MS.	178 (M^+)	192 (M^+)	220 (M^+)	192 (M^+)	220 (M^+)
	121	137	165	96	138
NMR.	[b]	[c]	[c]	[b]	[b]
H—C(7)	2.92 ($t \times d$)	2.75 ($d \times d$)	2.70 ($d \times d$)		
H_a—C(8)	2.06 (m)	1.76 (m)	1.75 (m)	H—C(8) 2.40 (d)	2.33 (d)
H_b—C(8)	1.45 (d)	1.36 (d)	1.10 (d)		
H—C(1)	2.68 (m)		-	CH_3 0.95–1.16	0.70–1.04
H—C(2)	2.40 (m)	1.70 (d)	1.92 (d)		
H—C(4)	1.57 (s)	1.36 (s)	1.58 (s)		
H—C(9)	2.38 (m)	1.48 (AB)	1.45 (AB)		
CH_3	0.82–1.03	0.84–1.02	0.58–1.08	[d]	
	$J_{H_7,H_1} = 5.5$, $J_{H_7,H_{8a}} = 7.0$, $J_{H_7,H_2} = 5.5$, $J_{H_{8a},H_{8b}} = 9.5$, $J_{H_1,H_9} = 5.5$			[e]	$J_{H_3,H_8} = 8.7$ [e]

[a] In CCl_4. [b] In $CDCl_3$. [c] In C_6D_6. [d] Other protons not resolved. [e] From shift reagent experiment.

It had been shown that the orientation of addition of enones to polarized olefins is influenced by electronic and steric effects [6] [7]. In particular this had been discussed in the addition of compounds **5** [21] to isobutylene (*Scheme 3*), whereby

Scheme 3



the amount of 'electronically incorrect' adduct **7** augmented with increasing size of the substituent R on the β-carbon of **5** [7].

The distribution of products **3** and **4** (Table 2) seems to be influenced by the same factors. The decrease in the amount of **3** – which represents the 'electronically correct' product – is most probably due to the increasing interaction of R' with the *geminal* dimethyl groups on C(4) of **2**. Interestingly the overall quantum yield is rather insensitive to R', *i.e.* the quantum yield of formation of **4** *increases* with the size of R'. This is explicable in terms of an increase in the value of the rate constant in the first selective product forming step. This would be the exciplex formation if there are two distinct exciplexes in the reaction paths leading to **3** and **4**, or the primary bonding step, *i.e.* diradical formation, if there is a common exciplex. Such an increase in the value of a rate constant may be due to changes in the relative arrangement of the olefinic side chain and the C=C bond of the enone system, whereby the increasing size of R' favors the formation of **4**. However, it cannot be excluded that the electronic effect is only of minor importance to steric strain differences in the tricyclo products. This would then mean that the product ratio **3**:**4** is determined mainly by the ratio of the k_d-values of the diradicals, *i.e.* of the relative dissociation rates of these intermediates to give back starting material[2]).

The quantum yields for the formation of **3** (0.1–0.2) are greater than the corresponding ones for the addition of 4,4-dimethyl-2-cyclohexenone to olefins (0.02–0.05) [9]. Such a difference in efficiencies between an intramolecular and an analogous intermolecular reaction seems reasonable.

Finally, the effect of the solvent polarity is not very marked, but less **4** is formed in acetonitrile than in cyclohexane. This would mean that one intermediate in the formation **4** or the rate constant of its formation is more susceptible to the polarity of the environment than the corresponding intermediate or rate constant in the reaction path leading to **3**. Similar solvent effects on the orientation of addition of enones to olefins have been observed [7] and interpreted as due either to alternative primary bond formation sites or to dipole-dipole interactions of the reactants in their ground states which would be weakened in polar solvents. For the moment it would be speculative to correlate the observed solvent influence on the product ratio with any specific cause.

---

[2]) In order to obtain more information on this point, temperature dependence studies on the product ratio **3**:**4** are in progress. The results will be communicated in a forthcoming paper.

Experimental Part

Materials. **1** [12], allyl iodide [22], 2-bromomethyl-3-methyl-1-butene [23] and the 2 M solution of sodium bis(trimethylsilyl)amide in toluene [24] were synthetized according to literature procedures. 3-Iodo-2-methyl-1-propene was prepared from 3-chloro-2-methyl-1-propene by analogy to [22] and had b.p. 30–32°/18 Torr. Toluene (*Merck*) was of analytical grade. The solvents used for photolyses were of spectroscopic grade.

Preparation of **2**. A 2 M solution of sodium bis(trimethylsilyl)amide in toluene (15 ml, 0.03 mol) was added to a stirred solution of 2.76 g (0.02 mol) of **1** in 50 ml of toluene under a static N_2-atmosphere at room temp. After 3 h the alkyl halide (0.04 mol) was added. After 12 h the mixture was poured in 400 ml of water, the organic phase separated, washed with water and dried over $MgSO_4$. After removal of the solvent, **2** was isolated by bulb to bulb distillation. The purity was checked by GLC. (5% SE 30 on chromosorb G-AW-DMCS at 105–140°) and was found to be $>95\%$.

Photolyses. These were carried out by filtering the light of a *Phillips* HPK-125W mercury lamp through a $(Pb(NO_3)_2+NaBr)$-solution with a cut-off at 340 nm, at room temp. Before irradiation the solutions were flushed with N_2. In a typical run $3 \cdot 10^{-3}$ mol of **2** in 15 ml of solvent were irradiated for 16–18 h. The isolation of the photoproducts was achieved as follows: **3a** was distilled in a bulb tube (70°/0.5 Torr), while **3b** and **4b** as well as **3c** and **4c** were obtained pure by chromatography on silicagel (benzene) or by preparative GLC. (15% QF_1 on chromosorb G-AW-DMCS at 170–230°).

Quantum Yields. They were measured at 20° using an electronically integrating actinometer [25]. The decrease of starting material was monitored by UV. spectroscopy. Thus Ar-degassed solutions ($c_2 = 5 \cdot 10^{-2}$ mol/l) were irradiated in a UV. cell (3 ml) up to 10% conversion with light of $\lambda = 366$ nm and the spectra were periodically recorded in the range 310–420 nm. The loss of starting material was evaluated at 358 nm.

Financial support of the *Fonds National Suisse de la Recherche Scientifique* (Grant no 2301-0.75) is gratefully acknowledged.

REFERENCES

[1] *G. Büchi & I. M. Goldman,* J. Amer. chem. Soc. *79,* 4741 (1957).
[2] *J. Meinwald & R. A. Schneider,* J. Amer. chem. Soc. *87,* 5218 (1965).
[3] *F. W. Erman & T. W. Gibson,* Tetrahedron *25,* 2493 (1969).
[4] *D. Becker, M. Nagler & D. Birnbaum,* J. Amer. chem. Soc. *94,* 4771 (1972).
[5] *C. H. Heathkock & R. A. Badger,* Chem. Commun. *1968,* 1510.
[6] *P. de Mayo,* Accounts. chem. Research *4,* 41 (1971).
[7] *P. Margaretha,* Chimia *29,* 203 (1975).
[8] *V. Desobry & P. Margaretha,* Helv. *58,* 2161 (1975).
[9] *G. Vo Thi & P. Margaretha,* Helv. *59,* 2236 (1976).
[10] *J. M. Conia & A. LeGraz,* C. r. hebd. séances Acad. Sci. *250,* 3196 (1960).
[11] *G. A. Russel & G. R. Stevenson,* J. Amer. chem. Soc. *93,* 2437 (1971).
[12] *C. Paris, S. Geribaldi, G. Torri & M. Azzaro,* Bull. Soc. chim. France *1973,* 997.
[13] *J. J. Barieux & J. Gore,* Bull. Soc. chim. France *1971,* 1649.
[14] *U. Wannagat & H. Niederprüm,* Chem. Ber. *94,* 1540 (1961).
[15] *M. Rathke,* Org. Synth. *53,* 66 (1973).
[16] *G. Stork, J. O. Gardner, R. K. Boeckman & K. A. Parker,* J. Amer. chem. Soc. *95,* 2014 (1973).
[17] *J. Villieras, D. Payan, Y. Anguelova & J. F. Normant,* J. organometal. Chemistry *42,* C5 (1972).
[18] *J. J. Barieux, J. Gore & J. C. Richter,* Bull. Soc. chim. France *1974,* 1020.
[19] *D. I. Schuster & R. H. Brown,* Chem. Commun. *1976,* 28.
[20] *T. F. Thomas, B. Matuszewski & R. S. Givens,* J. phys. Chemistry *78,* 2637 (1974).
[21] *P. Margaretha,* Helv. *57,* 2237 (1974).
[22] *R. L. Letsinger & J. G. Traynham,* J. Amer. chem. Soc. *70,* 2818 (1948).
[23] *D. H. R. Barton, T. Shiori & D. A. Widdowson,* J. chem. Soc. C *1971,* 1968.
[24] *C. R. Krüger & H. Niederprüm,* Inorg. Synth. *9,* 15 (1966).
[25] *W. Amrein, J. Gloor & K. Schaffner,* Chimia *28,* 185 (1974).