Table I. 3-Allylation of 2-Methylhydronaphthoquinone-1,4

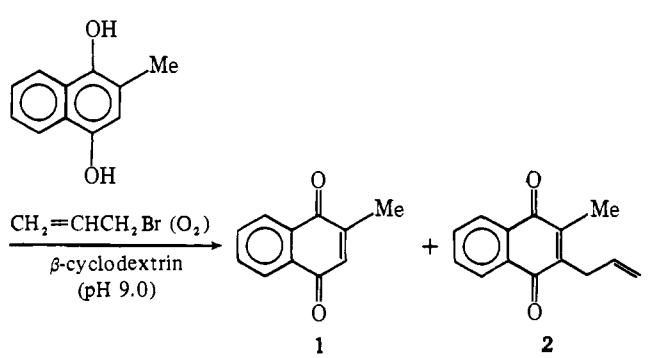
β-Cyclodextrin	M: R, Br	M: OH, Me, OH	Reaction period, h	Yield, % 1	Yield, % 2
5.0×10^{-2}	R = H, 2.0×10^{-1}	1.0×10^{-2}	9	54	40 (86)[a,b]
None	R = H, 2.0×10^{-1}	1.0×10^{-2}	9	14	16 (19)[a,c]
5.0×10^{-2}	R = Me, 2.0×10^{-1}	1.0×10^{-2}	9	22	60 (77)[a,b]
None	R = Me, 2.0×10^{-1}	1.0×10^{-2}	9	9	20 (22)[a,c]

[a] The yield based on a consideration of the amount of 1 recovered is shown in parenthesis. [b] The yield was very sensitive to the presence of a trace amount of oxygen. The values listed in the last two columns are the averages of several experiments. [c] Contaminated with considerable amounts of undefined by-products.

methanol was stirred at room temperature for 9 h under nitrogen atmosphere (nitrogen was carefully deoxygenated through a cupper column) in the dark. After the addition of 600 mL of water, 30 mL of concentrated HCl, and 24 mL of cyclohexylamine with cooling by ice, the mixture was extracted with eight portions of 45 mL of chloroform. The chloroform extracts were combined, washed with two portions of 60 mL of 1 N HCl, and dried over anhydrous sodium sulfate. Evaporation of chloroform, followed by column chromatography (silica gel, petroleum ether–ethyl acetate, 10:1), gave 216 mg (68% based on 2-methylhydronaphthoquinone-1,4 and 96% based on the consumed starting material) of 2-methyl-3-allylnaphthoquinone-1,4, **2**, and 75.6 mg (29% of the starting material used) of 2-methylnaphthoquinone, **1**. The allylation was also carried out in the absence of β-cyclodextrin under similar conditions, as a standard experiment.

Since the yield of the product was still sensitive to the presence of the trace amount of oxygen present in the "purified" nitrogen employed, the average yields for several independent runs were calculated based on the NMR analysis and are listed in the Table I. Thus, chloroform solutions of the crude products obtained as described above were dried over anhydrous sodium sulfate, and chloroform was carefully replaced by carbon tetrachloride. The NMR determination was made on the peaks for the vinyl proton (δ 4.93–5.20) and 3 proton of methylnaphthoquinone (6.80)[6] by using 1,2-dichlorethane (4.7) as a standard. The results of the NMR determination were in a good agreement with the preparative determination. The yields of **2** in repeated experiments are 92, 82, 86, and 84% with β-cyclodextrin and 18, 19, 15, and 13% without β-cyclodextrin.

That the yield of the vitamin K_1 or K_2 analogue formed through the inclusion complex was considerably higher than under the usual conditions indicates that β-cyclodextrin plays a significant role in the present allylation, as if it were a "vitamin K_1 (K_2) synthetase". The crotyl group was similarly introduced into the 3 position by the "vitamin K-synthetase model" (see Table I).



1 **2**

Vitamin K_1 was also prepared from methylnaphthohydroquinone by treatment with potassium hydride or potassium methoxide and alkenyl bromide in toluene followed by silver oxide oxidation,[7] but the yield was rather low. The marked catalytic effect of the cyclodextrin shown here seems to have its origin in the increase in nucleophilicity of the carbon atom on naphthohydroquinone monoanion[8] included in the cyclodextrin cavity ("base effect"),[9] which was also shown to be significant for the accelerated dehydrobromination (as well as the hydrolysis) of β-bromomethylnaphthalene in aqueous alkaline solution in the presence of β-cyclodextrin,[10] and in the protection[11] against oxidative cleavage of the included naphthoquinone derivatives. Detailed quantitative analysis of these two possible contributing factors are now under way.

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Trans → Cis Photoisomerization of *all-trans*-Retinal

Sir:

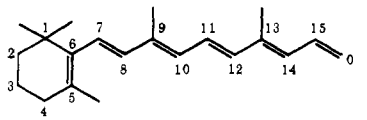
During their pioneering studies of the visual protein rhodopsin Wald, Hubbard, and coworkers[1-3] first examined the photochemical properties of the isomeric retinals in solution. A number of quantitative studies on the cis-trans photoisomerization of the retinals have since been reported,[4-7] in-

Table I. Photoisomerization Products of *all-trans*-Retinal

Solvent[a]	Excitation wavelength, nm[b]	Primary retinal photoproduct, rel ratio[c]
Ethanol	430, 390, 350, 310	7-cis:9-cis:11-cis:13-cis (1:10:30:60)
Hexane	430, 390, 350, 310	9-cis:13-cis (1:4)
	270	9-cis:13-cis (1:11)

[a] 5.0×10^{-5} M retinal in ethanol; 4.6×10^{-5} M retinal in hexane. [b] 7-nm band pass, 150-W Xe lamp. [c] Corrected for isomer response at 365-nm detection; average of several trials; <5% conversion.

cluding the quantum yields upon direct excitation[4,5] and triplet sensitization,[5-7] and the photoisomerization products.[1-3,5,6] We previously employed high pressure liquid chromatography (HPLC) to analyze the primary photoproducts in the solution photoisomerization of five retinal isomers.[5] We reported that upon 350-nm irradiation of *all-trans*-retinal (**1**) in hexane or



all-trans-retinal (**1**)

methanol to conversions <5%, 13-*cis*-retinal was the only observed photoproduct. This result was contradictory to one of Wald, Hubbard, and coworkers[1-3] who found that 11-*cis*-retinal was formed upon photolysis of **1** to a steady-state mixture in ethanol using light of wavelengths >410 nm. It was suggested that these differing photochemical results could be accounted for if a wavelength dependent photoisomerization were present for **1** since it is known that the low temperature fluorescence[8-12] quantum yield of **1** exhibits an excitation energy dependence. Thus, we have made a quantitative investigation of the trans → cis photoisomerization of **1**.

all-trans-, 9-*cis*-, and 13-*cis*-retinal (Sigma Chemical Co.) were purified to >99% by HPLC methods. 11-*cis*-retinal (a generous gift of the Hoffmann-La Roche Chemical Co.) was used without further purification. Absorption spectra were recorded on a Cary 14 spectrophotometer. Aerated samples[13] were irradiated in quartz cuvettes using the 150-W Xenon lamp and 1/4 m monochromator of an Aminco-Bowman spectrofluorimeter. A Waters Model ALC/GPC 204 liquid chromatograph was employed to analyze the photolysis products. Samples were analyzed using two 1 ft × 1/4 in. μ-Porasil columns, 1-2% diethyl ether/hexane, and 365-nm detection. The hexane photolysis solutions were analyzed directly, while ethanol (distilled from CaH_2) and methanol solutions were evaporated to dryness, diluted with hexane, and analyzed. Peak areas were determined by multiple planimeter tracings, correcting for individual isomer response. Photoproducts were characterized by HPLC retention times and quantum yields determined using ferrioxalate actinometry[14] and the equation employed in our previous study.[5]

The quantum yields and products of the trans → cis photoisomerization of **1** in hexane and ethanol were determined as a function of the excitation wavelength when **1** was irradiated at room temperature with monochromatic light in the 270-430-nm (Table I) region. The retinal isomer distribution when solutions of **1** or 13-*cis*-retinal were irradiated in ethanol or hexane to photoequilibrium was also determined (Table II). The following results have been obtained upon direct excitation of **1** in hexane at room temperature: (a) the absolute quantum yield of the trans → cis photoisomerization process (ϕ_{PI}) is excitation energy *independent* upon photolyses with monochromatic light in the 270-430-nm region with $\phi_{PI} = 0.08 \pm 0.02$, a value similar to that previously reported;[7] (b) 13-*cis*-retinal is the major primary photoproduct, but 9-*cis*-retinal is formed in good yields;[15] (c) the ratio of the 9-*cis*- to 13-*cis*-retinal photoproducts is excitation energy independent in the 310-430-nm region, but differs upon 270-nm excitation; and (d) 9-*cis*,13-*cis*-retinal is present in the photoequilibrium mixture established by 390- or 430-nm irradiation of **1** for 1-2 h in hexane.[16,17] Upon irradiation of **1** in ethanol solutions, the following results have been obtained: (a) ϕ_{PI} is excitation energy *independent* in the 310-430-nm region; (b) 11-*cis*-retinal[15] is formed as a primary major photoproduct along with the 13-cis and 9-cis isomers; (c) 7-*cis*-retinal[18,19] appears to be formed as a primary, but minor photoproduct; and (d) the photoproduct ratio is excitation energy independent upon irradiation in the 310-430-nm region. Less extensive studies of the photoisomerization of **1** in methanol yielded results similar to those obtained in ethanol, including the formation of 7-*cis*-retinal.[18,19]

The present results confirm the findings of Wald, Hubbard, and coworkers,[1-3] who found that photolysis of dilute ethanol solutions of **1** to photoequilibrium resulted in the formation of ~50% *cis*-retinals,[1] with 11-*cis*-retinal being 25% of the mixture.[3] In addition, however, we note the formation of the sterically hindered 7-*cis*-retinal isomer.[19] The 7-cis isomer of retinal combines with cattle opsin to form a stable rhodopsin analogue,[20] and some aspects of the photochemistry of 7-*cis*-retinal have been reported.[21] 7-Cis isomers are present in the photostationary states of trienes, but reported absent in longer chained polyenes upon sensitized irradiation to photoequilibrium.[21] 7-*cis*-Retinal appears to be present in ~1% yields in the room temperature direct excitation of **1** in ethanol and methanol.

An excitation energy dependence in the trans → cis photoisomerization of **1** is reflected by the change in the product ratios observed upon irradiation at 270 nm. No dependence is reflected in measurements of ϕ_{PI}; however, this result probably demonstrates the accuracy with which product ratios can be determined relative to quantum yields. Since the photoisomerization of **1** is thought to occur via the excited singlet state[5,7] and the intersystem crossing quantum yield (ϕ_{ISC}) is independent of the excitation energy,[22] ϕ_{ISC} (265 nm) = 0.4 ± 0.06,[22] and ϕ_{ISC} (first band) = 0.5 ± 0.1,[7,22-24] no variation in ϕ_{PI} is to be expected over this excitation energy range.

Finally, because of the large variation of the primary photoproducts of **1** with solvent polarity and concentration,[1,3] it is expected that the yields of 7-*cis*- and 11-*cis*-retinal may be further increased. The maximization of 11-*cis*-retinal upon irradiation of **1** is synthetically important.

Table II. Isomer Distribution of Retinals at Photoequilibrium

Solvent[a]	Excitation wavelength, nm[b]	Percentage retinal isomer[c]					
		all-trans	7-cis	9-cis	11-cis	13-cis	9,13-di-cis
Ethanol	430	45	1	12.5	20	21.5	1
	390	52.5	0.5	7	19.5	20.5	1
Hexane	430	62	0	5	0	31	2
	390	70	0	5	0	24	1

[a] 5.0×10^{-5} M retinal in ethanol; 4.6×10^{-5} retinal in hexane. [b] 10-nm band pass, 150-W Xe Lamp, 2 h. [c] Corrected for isomer response at 365-nm detection.

Note Added in Proof. 7-*cis*-Retinal is formed upon photolysis of **1** in polar solvents.[25]

Acknowledgments. We wish to express our thanks to the Hoffmann-La Roche Chemical Co. for their generous gift of 11-*cis*-retinal and to the National Society for the Prevention of Blindness, Pennsylvania Lions Eye Research Foundation, and the Health Research and Services Foundation for support of this research.

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(15) The failure to detect these isomers in our previous study[5] may be the result of a number of factors. In that study the photoconversions of **1** were 1–2%. Quantum yields were obtained from the peak areas of these chromatograms. Since the peak corresponding to **1** was kept on scale, it is likely that a small amount of 9-*cis*-retinal could have gone unnoticed in the hexane solutions (or 11-*cis*-retinal in the methanol solutions). We specifically sought to observe the presence of these isomers in the present experiments and were aided by the increased sensitivity of the Model 440 absorbance detector, compared to the Model 100 absorbance detector used earlier. The increased sensitivity is approximately two orders of magnitude. One nanogram of **1** can be observed ($S/N = 3$) using the Model 440 absorbance detector, 365-nm detection. Since the conversions of **1** were >5% in this study and only one-bond isomerizations were observed (Table I), we do not feel that the observation of 9-*cis*- or 11-*cis*-retinal is due to the method of irradiation. We did notice, however, when solutions of **1** in ethanol (or methanol) were irradiated and stored in aerated vials in the freezer for several days, that the amount of detectable 11-*cis*-retinal had diminished considerably. The presence of water in these alcoholic solvents also appears to diminish the amount of 11-*cis*-retinal observed upon irradiation of **1**.
(16) A peak with a retention time shorter than that of 13-*cis*-retinal is present in the photoequilibrium mixture.
(17) Prolonged photolysis of the photoequilibrium mixtures reported in Table II results in the loss of absorption above ~300 nm.
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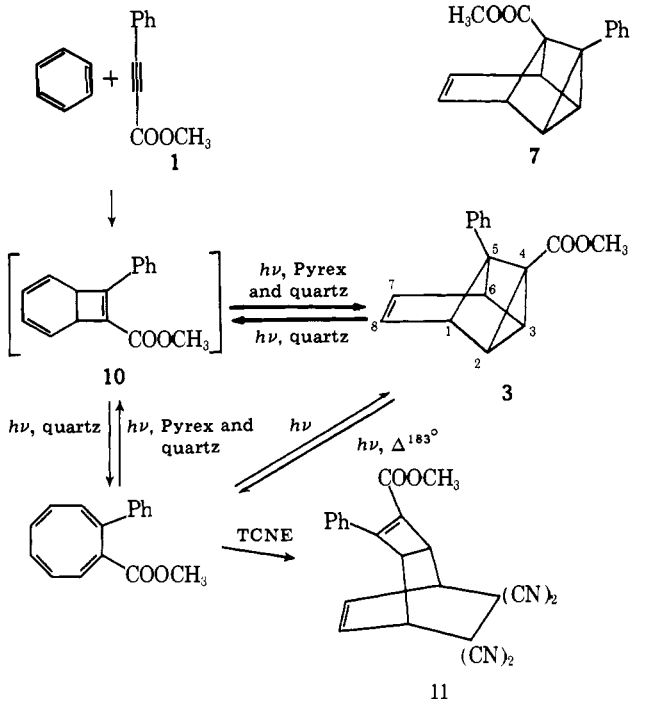
Photoaddition of Methyl Phenylpropiolate to Benzene.[1] Formation of a Tetracyclo[3.3.0.0^{2,4}.0^{3,6}]octa-7-ene

Sir:

Few photocycloaddition reactions are as well studied as those of acetylenes to aromatic compounds.[2–4] It is unanticipated therefore that one should discover new behavior in the photochemical system—alkyne and benzene. We have made such a discovery, however, and report a new ring system from the photochemical addition of methyl phenylpropiolate to benzene.

Scheme I



Methyl phenylpropiolate (**1**) and benzene is reported[3] to give 1-carboxymethyl-8-phenylcyclooctatetraene (**2**) when irradiated at 253.7 nm or at wavelengths >290 nm, where only the acetylene absorbs light to a significant degree. The English workers reported no perceptible difference in the amount of cyclooctatetraene formed under different conditions.

Unable to confirm Bryce-Smith's results, we obtained instead a previously unknown compound when a 5×10^{-3} M solution of **1** in benzene was irradiated. We identified the new product as 4-carboxymethyl-5-phenyltetracyclo-[3.3.0.0^{2,4}.0^{3,6}]octa-7-ene (**3**). (Irradiations were carried out under a N_2 atmosphere for 3 days with a Hanovia 450-W medium-pressure mercury lamp through a Pyrex filter. Compound **3** separated from residual **1** by column chromatography over silica gel and was isolated in 85% yield.)

Photoproduct **3** was found to be isomeric with cyclooctatetraene **2** by elemental analysis[5] and the parent ion (*m/e* 238) confirmed its molecular weight. Apart from McLafferty-type cleavage reactions induced by the ester group, the most important mode of mass spectral fragmentation was formation of the ion at *m/e* M − 78. The infrared absorption of the carbonyl group at relatively low wavenumber proves cyclopropyl conjugation:[6a] IR (CCl_4, cm^{-1}) 3050, 1715, 1440, 1395, 1260, 1235, 1195, 1160, 1150, 1120, 1108, 1087, 975, 952, 870, 738, 714, 703, 675. The ^{1}H NMR spectrum of **3** in $CDCl_3$ consisted of two triplets, vinyl protons at δ 6.12 (2 H, J = 2 Hz, H_7 and H_8) and another at 3.02 (2 H, J = 2 Hz, H_2 and H_3), a multiplet centered at 3.93 (2 H, H_1 and H_6), and two singlets at 3.65 (3 H, $COOCH_3$) and 7.29 (5 H, Ar). This spectrum suggests a high degree of symmetry. That **3** is symmetrical is further revealed by its ^{13}C NMR spectrum in $CDCl_3$, consisting of the following absorptions:[7] 33.61 (d, $C_{2,3}$), 35.31 (s, C_4), 51.08 (q, C_{methyl}), 54.59 (d, $C_{1,6}$), 73.71 (s, C_5), 127.08 (d, C_{Ar}), 127.81 (d, C_{Ar}), 134.63 (d, $C_{7,8}$), 136.06 (s, C_{Ar}), and 171.09 (s, C_{ester}).