Tetrahedron Letters No.13, pp. 1419-1424, 1966. Pergamon Press Ltd.
Printed in Great Britain.

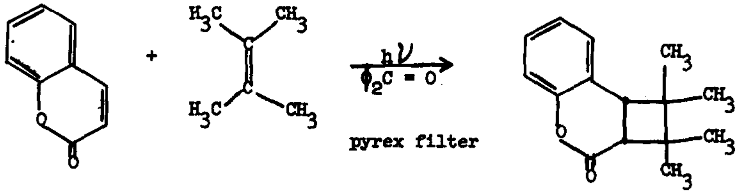
SOME PHOTOCHEMICAL CYCLOADDITION REACTIONS OF COUMARIN

J. William Hanifin and Elliott Cohen
Organic Chemical Research Section, Lederle Laboratories
a Division of American Cyanamid Company, Pearl River, N. Y.

(Received 31 January 1966)

Recently a number of addition reactions of photochemically excited molecules to extramolecular bonds have been described (1). We would like to report the sensitized photoaddition reaction of coumarin to both activated and unactivated, extramolecular double bonds (2). The reactions of coumarin with tetramethylethylene, cyclopentene and ketene diethyl acetal are discussed.

A solution of coumarin (.021 mole), tetramethylethylene (.211 mole), benzophenone (.004 mole) and dioxane (.083 mole) was irradiated through pyrex glass with a 500-watt mercury arc lamp. A 51 per cent yield of the coumarin-tetramethylethylene 1:1 adduct I, m.p. 81°, was obtained by this procedure. The infrared spectrum of the adduct shows strong carbonyl absorption at 5.73μ. The n.m.r. spectrum,* in accord with the desired adduct, shows four methyl groups at 8.73, 8.78, 8.98 and 9.25 τ (singlets), four aromatic hydrogens at 2.9 τ (multiplet) and two cyclobutane hydrogens, in an AB pattern, at 6.62 and 6.82 τ (JAB = 10 c.p.s.).



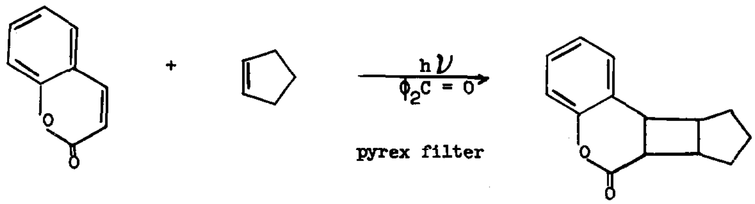
I

---

*All n.m.r. spectra were taken by Mr. W. Fulmor and group on a Varian A-60 Spectrophotometer.

These photoaddition reactions require the presence of the triplet state sensitizer. Competing with the desired addition is the reaction of an excit benzophenone triplet with olefin to give the corresponding oxetane (3). No appreciable amount of coumarin dimer was isolated during this reaction. Bas on the n.m.r. spectrum of I, it is believed that the rings are fused cis. T large coupling constant (J = 10 c.p.s.) obtained for the cyclobutane hydroge is in agreement with that found for cis cyclobutane hydrogens in a similar system (4). In addition, this large coupling constant requires a dihedral angle of approximately 0° or 180° between the two cyclobutane hydrogens (5) an angle of 180° does not seem reasonable for this particular fused system.

Mercury arc irradiation of a solution of coumarin (.028 mole), cyclopen (.283 mole), benzophenone (.005 mole) and dioxane (.059 mole) gave a 50 per yield of the coumarin-cyclopentene 1:1 adduct II, m.p. 139°. The infrared spectrum of the adduct contains a strong carbonyl absorption at 5.71μ. The n.m.r spectrum shows four aromatic hydrogens at 2.9 τ (multiplet), two cyclobutane hydrogens at 6.2 τ (multiplet), two cyclobutane hydrogens at 6.8 (multiplet), and six methylene hydrogens at 8.0 - 8.9 τ (multiplet).

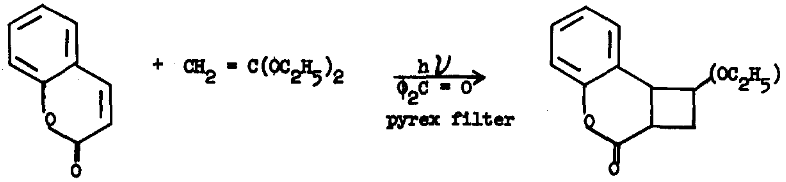


II

As with the previous reaction, the triplet state sensitizer is necessary for the reaction. The formation of an oxetane from benzophenone and cyclopentene again appears to be a competing reaction. In this photo-addition, a minor product is the trans-head-to-head coumarin dimer (6). In the absence of benzophenone, a small amount of the cis-head-to-head coumarin dimer was detected (7).

Anet (7) had reported that irradiation of coumarin in ethanol solution produces the cis-head-to-head coumarin dimer. Schenck (6) has shown that irradiation of benzene solutions containing coumarin and benzophenone led to the formation of the trans-head-to-head dimer. Hammond (8) has since demonstrated that in the absence of a triplet sensitizer the cis-head-to-head coumarin dimer arises from attack of an excited coumarin singlet on ground state coumarin. In the presence of a triplet state sensitizer, the trans-head-to-head dimer arises from interaction of excited triplet coumarin with ground state coumarin. In the case of the sensitized cycloaddition reaction of coumarin with cyclopentene, it seems probable that attack of an excited coumarin triplet on ground state olefin is involved. The stereochemistry of the coumarin-cyclopentene adduct II is uncertain, however, the five- and six-membered rings are probably anti.

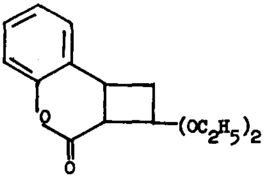
In the last photoaddition reaction examined, a solution of coumarin (.029 mole), ketene diethyl acetal (.190 mole), benzophenone (.006 mole) and dioxane(.06mole)was irradiated through pyrex glass with the 500-watt mercury arc lamp. A 41 per cent yield of the coumarin-ketene diethyl acetal 1:1 adduct III, b.p. 95-100°/.25 mm was obtained. The infrared spectrum of the adduct contains strong carbonyl absorption at 5.70μ. The n.m.r. spectrum shows two methyl triplets at 8.75 and 9.00 τ, four aromatic protons centered at 2.8 τ (multiplet), another broad complex multiplet at 6.1-7.0 τ, consisting of two cyclobutane hydrogens and the four methylene hydrogens of the ethoxy groups (two separate quartets). The two methylene cyclobutane hydrogens appeared at 7.33 τ and 7.30 τ, each as a doublet with couplin constants of $J = 7$ c.p.s. and $J' = 5$ c.p.s. respectively.



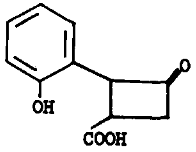
III

Once again experiments showed that the triplet state sensitizer is required. No appreciable amount of coumarin dimer was isolated during th reaction. Oxetane formation between benzophenone and ketene diethyl acetal is again observed as a competing reaction (9). A minor amount of ββ-diphenyl-β-hydroxy ethyl propionate was also isolated from this reacti

A choice between the two possible orientations for the coumarin-ketene diethyl acetal adduct, III and IV, can be made on chemical grounds Hydrolysis of III with dilute hydrochloric acid gives the keto-acid V, m.p. 140 - 1°, which under acid conditions and additional heating does no decarboxylate. The infrared spectrum of V contains strong carbonyl absorption at 5.59 and 5.78μ and broad hydroxy absorption at 3.0μ. The n.m.r. spectrum shows four aromatic hydrogens at 2.8 τ (multiplet) three cyclobutane hydrogens centered at 6.6 τ (multiplet) and one cyclobutane hydrogen at 5.25 τ split into a doublet ($J = 7$ c.p.s.).

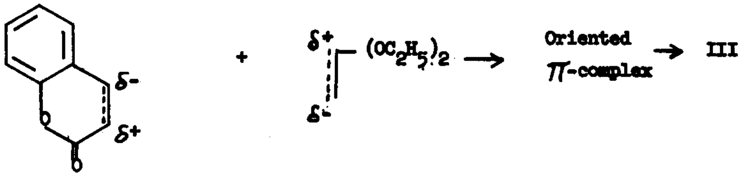


IV



V

In addition, structure III is in agreement with a recently postulated theory for some photoaddition reactions (1b). Namely, a π-complex is formed between the excited state of one molecule and the ground state of another, and the factor which controls orientation is the geometry of this intermediate π-complex. Recent calculations of charge distribution in the $n \rightarrow \pi^*$ excited state of planar α,β-unsaturated ketones indicate C_β is quite negative relative to $C\alpha$ (10). Experimentally, this appears to be true for the excited state of planar α,β-unsaturated lactones (coumarin).



References

1. (a) P. E. Eaton, J. Am. Chem. Soc., 84, 2454 (1962); (b) E. J. Corey, J. D. Bass, R. LeMahieu, and R. B. Mitra, J. Am. Chem. Soc. 86, 5570 (1964); (c) P. E. Eaton, Tetrahedron Letters No. 48, 3695 (1964); (d) D. Valentine, N. J. Turro, and G. S. Hammond, J. Am. Chem. Soc. 86, 5202 (1964).

2. A related type of photoaddition reaction for coumarin has been reported in the literature; see G. O. Schenck, W. Hartmann, S. Mannsfeld, W. Metzner and C. Kranch, Ber. 95, 1642-7 (1962).

3. D. R. Arnold, R. H. Hinman, A. H. Glick, Tetrahedron Letters No. 22, 1425 (1964).

4 G. M. Blackburn and R. J. H. Davis, Chem. Comm. No. 11, 215 (1965).

5. R. H. Bible, Jr., "Interpretation of NMR Spectra", Plenum Press, New York, N. Y., 1965, p. 36.

6. G. O. Schenck, I. von Wilucki, and C. H. Kranch, Ber., 95, 1409 (1962).

7. F. A. L. Anet, Can. J. Chem., 40, 1249 (1962).

8. G. S. Hammond, C. A. Stout, and A. A. Lamola, J. Am. Chem. Soc., 86, 3103 (1964).

9. The oxetane obtained in this reaction has been identified as 2-Propanone, 1,3-epoxy-1,1,diphenyl-,diethyl acetal. The chemical shift of the two methylene cyclobutane hydrogens is consistent with this assignment (3).

10. Calculations as cited by E. J. Corey (1b).