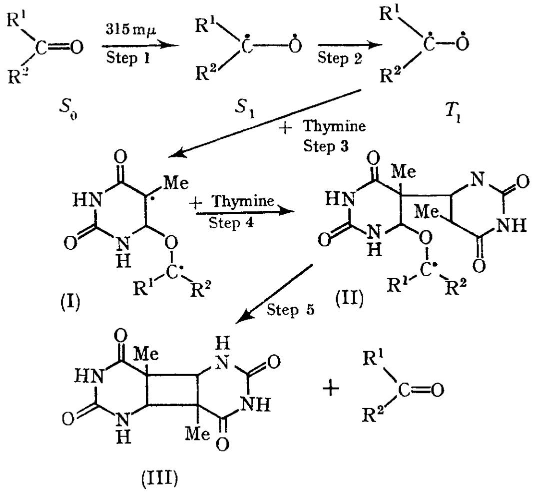
Mechanism of Photosensitized Dimerization of Pyrimidines

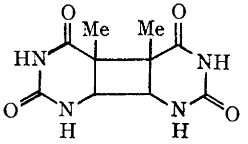
By A. KORNHAUSER,* J. N. HERAK, and N. TRINAJSTIĆ
(Institute "Rudjer Bošković", Zagreb, Yugoslavia)

PYRIMIDINES on irradiation by u.v. light ($\sim 260\ \mathrm{m}\mu$) undergo some typical photochemical reactions. Uracil[1] yields a dimer (a cyclobutane derivative) and a water addition product, *i.e.* 5,6-dihydro-6-hydroxyuracil, whereas thymine[2] gives its dimer as the main product. On the other hand, it was found recently that pyrimidines undergo a photosensitized dimerization;[3–5] acetone or acetophenone are the most commonly used sensitizers. The main difference between these two reactions is that in the photosensitized one only dimers could be found as the reaction products.[3,5] While the former reaction has been widely studied[6–8] the latter still lacks a qualitative as well as a quantitative approach. Lamola *et al.*[9] studied the photosensitized dimerization of thymine in DNA. They did not suggest a possible mechanism, but assumed a triplet thymine as the reactive species.

On the basis of the above experimental data and some theoretical studies, we suggest the following possible reaction scheme of the photosensitized dimerization of pyrimidines:



Since u.v. light of $315\ \mathrm{m}\mu$ does not excite pyrimidines, it is obvious that the ketone molecule plays the role of transferring energy. In particular, the carbonyl group is responsible for the photosensitive action. In this case two types of transitions can occur: π–π^* and n–π^*. The n–π^* transitions are of low intensity[10,11] and they are induced at wavelengths higher than $300\ \mathrm{m}\mu$. From the fact that the light of $315\ \mathrm{m}\mu$ is used in these experiments[5] and that the efficiency of photodimerization is low[9] we conclude that the n–π^* transitions are those which promote carbonyl groups from the S_0 to the S_1 state (Step 1). Step 2 is just a rapid radiationless transition from S_1 to T_1. The triplet state rather than the singlet state takes part in the reaction of the sensitizer with the pyrimidine base. The reasons are as follows: firstly, the triplet state has a lower energy and is more stable than the corresponding singlet state.[12] Secondly, the reaction can proceed only *via* the triplet state since experiments were carried out with dilute solutions,[5] and only the moderate life-time of the triplet state can provide enough time for the reaction. Finally, the triplet state has its electrons almost localized on the neighbouring atoms.[8] This particular property of the triplet state is responsible for the reaction of the excited carbonyl group with the pyrimidine molecule in its ground state. The attack can take place at only one position of the thymine ring. The remaining two electrons have parallel spins and therefore repel each other. Thus, it can be regarded as a pseudoradical reaction (Step 3). We have not been able so far to find any other possible reaction mechanism which could give a better fit to the known experimental facts. Any polar structure as an intermediate may be ruled out, since no water adduct has ever been isolated from pyrimidines thus irradiated.



(IV)

From the considerations of free valences we conclude that position 6 of the thymine molecule (having a free valence of 0·455† or 0·536‡) is a more probable site for the primary reaction than position 5 (free valence 0·366† or 0·496‡). In fact, from the reaction products it can be seen that the

---

† Calculated by HMO method.

‡ Calculated by the open-shell SCF MO method (ref. 7).

carbonyl group reacts also with C-5 of thymine but to a lesser extent.

Complex (I) behaves like a biradical (the exchange term being very small). It reacts like a radical with another thymine molecule (Step 4) forming an unstable complex (II) which is converted into a dimer (III). Besides compound (III), other stable species like (IV) or oxetans have also been found,[3] thus indicating that other reactions are also possible but less probable.

We thank Professor A. Wacker (Frankfurt-am-Main) for helpful suggestions.

(*Received, July 4th,* 1968; *Com.* 890.)

---

[1] R. L. Sinsheimer and R. Hastings, *Science*, 1949, **110**, 525; S. Y. Wang, M. Apicella, and B. R. Stone, *J. Amer. Chem. Soc.*, 1956, **78**, 4180; A. Wacker, A. Kornhauser, and L. Träger, *Z. Naturforsch.*, 1965, **20b**, 1043.

[2] R. Beukers, J. Ijlstra, and W. Behrends, *Rec. Trav. chim.*, 1958, **77**, 729; A. Wacker, H. Dellweg, and D. Weinblum, *Naturwiss.*, 1960, **47**, 477.

[3] I. Wilucki, H. Matthäus, and C. H. Krauch, *Photochem. and Photobiol.*, 1967, **6**, 497.

[4] D. Elad, C. Krüger, and G. M. J. Schmidt, *Photochem. and Photobiol.*, 1967, **6**, 495.

[5] C. H. Krauch, D. M. Krämer, P. Chandra, P. Mildner, H. Feller, and A. Wacker, *Angew. Chem.*, 1967, **79**, 944.

[6] R. Beukers and W. Behrends, *Biochim. Biophys. Acta*, 1961, **49**, 181; E. Stumpf-Kulikowska, D. Shugar, and J. W. Boag, *Photochem. and Photobiol.*, 1967, **6**, 41.; A. A. Lamola and J. P. Mittal, *Science*, 1966, **154**, 1560.

[7] V. I. Danilov, O. V. Shramko, and G. G. Dyadyusha, *Biofizika*, 1967, **12**, 544.

[8] V. I. Danilov, *Photochem. and Photobiol.*, 1967, **6**, 233; V. I. Danilov, Y. A. Kruglyak, V. A. Kupriyevich, and O. V. Shramko, *ibid.*, 1968, in the press.

[9] A. A. Lamola and T. Yamane, *Proc. Nat. Acad. Sci. U.S.A.*, 1967, **58**, 443.

[10] H. H. Jaffe and M. Orchin, "Theory and Application of Spectroscopy", Wiley, New York, 1962, p. 179.

[11] J. N. Murrel, "The Theory of the Electronic Spectra of Organic Molecules", Methuen, London, 1963, pp. 158–168.

[12] N. Turro, "Molecular Photochemistry", Benjamin, New York, 1965, p. 19.