

A MULTI-STEP PHOTOREACTION OF 5-FORMYL-1,3-DIMETHYLURACIL
WITH INDOLE IN THE SOLID STATE

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Abstract - Irradiation of the mixed crystals between 5-formyl-1,3-dimethyluracil (1) and indole (2) gave 5-(bis-1-indolyl)methyl-1,3-dimethyluracil (3), whereas 1,3-dimethyluracil was the sole product in the photolysis of 1 and 2 in solution.

A recent trend in photochemical research is directed to photochemistry of supramolecular assemblies, namely more complex systems than simple solutions.¹⁻⁴ We have made various approaches to this problem focusing photochemistry of organic molecules in the solid state.⁵⁻¹³ Among these approaches, we have been particularly interested in bimolecular photoreaction between two different organic molecules in the solid state, since a relatively few attention has been made to this field.¹⁴ For example, irradiation of the mixed crystals of indole and phenanthrene gave an adduct in the solid state but no reaction occurred in organic solvents.⁷ We now describe a novel multi-step photoreaction of 5-formyl-1,3-dimethyluracil with indole occurring only in the solid state.

Mixed crystals, prepared by resolidifying the melt of a mixture of 5-formyl-1,3-dimethyl-uracil (1) and indole (2) crystals (molar ratio 1 : 3), were irradiated with a high-pressure mercury lamp for 4 hours gave a photoproduct 3 in 40 % yield. The structure of 3 was assigned as 5-(bis-1-indolyl)methyluracil on the basis of its spectral data and finally confirmed by an X-ray crystallographic analysis (Figure 1, Table 1-2). The solution photochemistry of 5-formyl-1,3-dimethyluracil (1) was quite different from the solid-state one. Irradiation of 1 in acetonitrile or methanol with a high-pressure mercury lamp under nitrogen gave 1,3-dimethyluracil (4) as the major product in the presence of indole and no formation of 3 was observed. It is of interest that 1 having a conjugated enal group underwent neither usual [2 + 2] cycloaddition nor photoreduction in solution.

Since the formation of 3 in the solid state appeared to involve a two-step photo-reaction between 1 and two molecules of indoles, the time course of the reaction was examined. The result is shown in Figure 2 indicating the formation of an intermediate. However, the isolation of this intermediate was unsuccessful owing to its instability on a silica gel column. Although the structure of the intermediate remains to be elucidated, the intermediary formation of an indole oxetane **5**¹⁵ may be plausible which will react photochemically or thermally to give 3. The proximity effect of the substrate molecules in the mixed crystal appears to be responsible for the facile formation of 3.

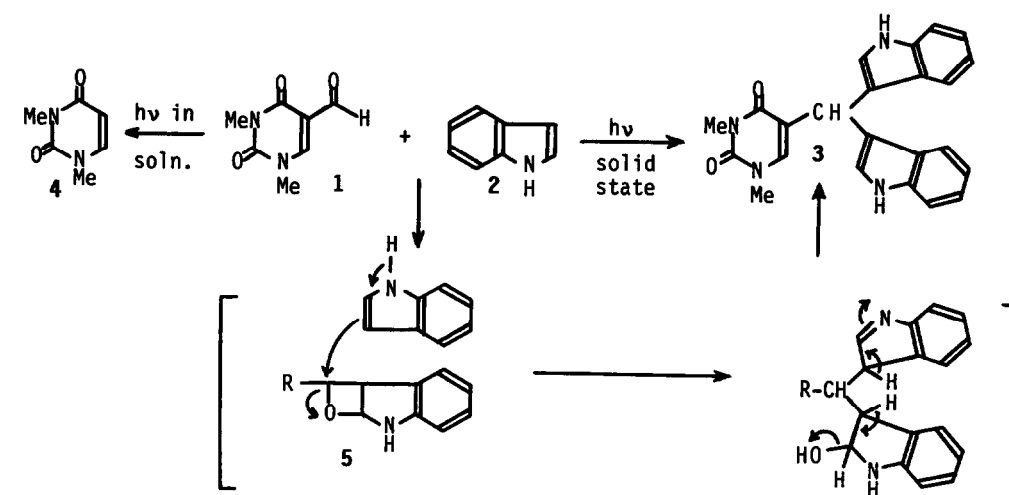


Table 1. Positional parameters for non-hydrogen atoms of 3 with estimated standard deviations in parentheses.

Atom	x	y	z	Beq.(02)
C	1.0372(4)	-0.0283(5)	0.2391(2)	3.1(1)
N11	0.9956(4)	0.0332(5)	0.1647(2)	5.1(1)
C12	0.8947(4)	-0.0389(5)	0.1155(2)	3.6(1)
N13	0.8579	0.0238(4)	0.0492(2)	3.67(9)
C14	0.9135(5)	0.1411(5)	0.0282(2)	4.0(1)
C15	1.0057(4)	0.2011(4)	0.0770(2)	2.25(9)
C16	1.0442(4)	0.1506(5)	0.1432(3)	3.5(1)
O17	0.8446(3)	-0.1463(4)	0.1283(2)	5.08(9)
C18	0.7506(5)	-0.0396(6)	-0.0017(3)	5.6(1)
O19	0.8795(3)	0.1849(4)	-0.0330(2)	4.91(9)
C20	1.0611(6)	0.3275(7)	0.0572(3)	5.8(2)
C22	1.1697(4)	0.0181(5)	0.2747(3)	3.2(1)
C23	1.2847(4)	-0.0024(5)	0.2509(2)	3.1(1)
C24	1.3158(4)	-0.0642(6)	0.1921(3)	3.8(1)
C25	1.4396(5)	-0.0648(6)	0.1851(3)	4.7(1)
C26	1.5346(4)	-0.0032(6)	0.2367(3)	4.9(1)
C27	1.5066(5)	0.0598(6)	0.2952(3)	4.7(1)
C28	1.3815(4)	0.0613(5)	0.3013(3)	3.6(1)
N2	1.3289(4)	0.1151(4)	0.3534(2)	4.4(1)
C21	1.2016(5)	0.0904(6)	0.3365(3)	4.0(1)
C32	0.9444(4)	0.0111(5)	0.2843(2)	3.6(1)
C33	0.9275(4)	-0.0646(6)	0.3453(3)	3.9(1)
C34	0.9723(6)	-0.1917(6)	0.3753(3)	5.4(1)
C35	0.9374(6)	-0.2340(8)	0.4367(3)	7.4(2)
C36	0.8596(6)	-0.1540(8)	0.4679(3)	7.9(2)
C37	0.8158(5)	-0.0267(8)	0.4413(3)	6.9(2)
C38	0.8505(5)	0.0175(6)	0.3785(3)	5.0(1)
N3	0.8224(4)	0.1369(5)	0.3386(3)	5.5(1)
C31	0.8788(5)	0.1310(6)	0.2815(3)	4.4(1)

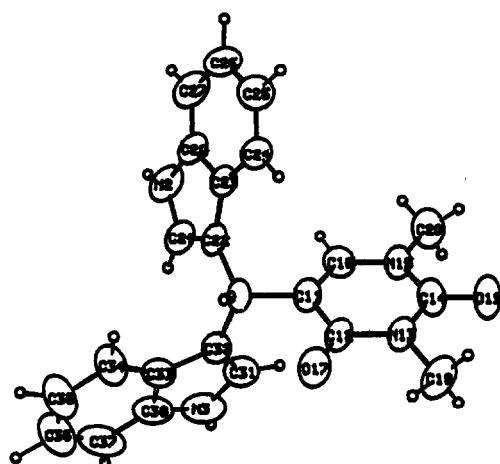


Figure 1. Molecular structure of 3.

Experimental

Melting points are uncorrected. ^1H -NMR spectra were measured on a JEOL PMX-60 spectrometer using TMS as an internal standard. IR were measured on a PYE UNICAM, sp3-300 spectrophotometer. Mass spectra were recorded on a 7070E-HE mass spectrometer. Column chromatography was carried out on silica gel (Qing Dao 300).

Photoreaction of 5-formyl-1,3-dimethyluracil (1) with indole (2) in the solid state.

The mixed crystal was prepared by melting a mixture of 1 (0.168 g, 0.10 mmol) and 2 (0.351, 0.30 mmol) followed by cooling the melt. The mixed crystal was ground to a

Table 2. Bond distances (Å) and bond angles (°) of 3 with estimated standard deviations in parentheses.

C-N11	1.532(7)	C14-O19	1.239(5)	C27-C28	1.384(7)
C-C22	1.517(6)	C15-C16	1.350(6)	C28-N2	1.366(7)
C-C32	1.518(8)	C15-C20	1.449(8)	N2-C21	1.366(6)
N11-C12	1.459(9)	C22-C23	1.433(7)	C32-C31	1.353(7)
N11-C16	1.351(7)	C22-C21	1.363(6)	C33-C34	1.398(8)
C12-N13	1.395(6)	C23-C24	1.390(7)	C33-C35	1.384(9)
C12-O17	1.221(6)	C23-C28	1.407(6)	C35-C36	1.38(2)
N13-C14	1.383(6)	N3-C31	1.378(8)	C36-C37	1.38(2)
N13-C18	1.482(6)	C25-C26	1.400(7)	C37-C38	1.414(8)
C14-C15	1.344(6)	C26-C27	1.378(8)	C38-N3	1.383(8)
N11-C-C22	111.5(4)	C16-C15-C20	119.8(4)	C-C32-C33	124.6(4)
N11-C-C32	110.4(4)	N11-C16-C15	122.3(4)	C-C32-C31	126.8(5)
C22-C-C32	110.2(4)	C-C22-C23	128.0(4)	C33-C32-C31	108.0(5)
C-N11-C12	117.0(5)	C-C22-C21	125.6(4)	C32-C33-C34	133.9(5)
C-N11-C16	124.1(4)	C23-C22-C21	106.4(4)	C32-C33-C38	106.6(5)
C12-N11-C16	119.0(4)	C22-C23-C24	134.9(4)	C34-C33-C38	119.6(6)
N11-C12-N13	114.6(4)	C22-C23-C28	106.5(5)	C33-C34-C35	118.7(6)
N11-C12-O17	125.2(5)	C24-C23-C28	118.5(4)	C34-C35-C36	121.3(6)
N13-C12-O17	120.4(4)	C23-C24-C25	119.9(4)	C35-C36-C37	122.1(6)
C12-N13-C14	124.6(4)	C24-C25-C26	120.5(5)	C36-C37-C38	117.1(6)
C12-N13-C18	117.2(5)	C25-C26-C27	120.9(5)	C33-C38-C37	121.4(7)
C14-N13-C18	118.1(4)	C26-C27-C28	118.0(4)	C33-C38-N3	107.2(5)
N13-C14-C15	116.8(4)	C23-C28-C27	122.1(5)	C37-C38-N21	131.5(6)
N13-C14-O19	120.1(5)	C23-C28-N2	108.0(5)	C38-N3-C31	109.4(5)
C15-C14-O19	123.0(5)	C27-C28-N2	129.8(4)	C32-C31-N3	108.9(5)
C14-C15-C16	122.5(4)	C28-N2-C21	108.6(4)		
C14-C15-C20	117.7(4)	C22-C21-N2	110.3(5)		

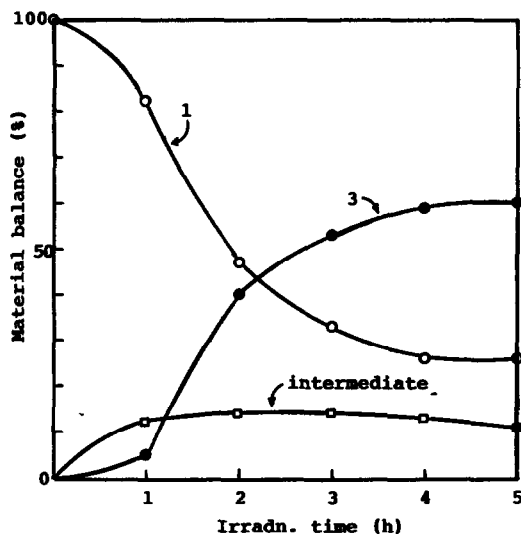


Figure 2. Time course of the photoreaction of 1 in the presence of an excess of 2 in the solid state.

fine powder, spread on the inner wall of a test tube and irradiated with a 300 W high-pressure mercury lamp for 4 h at room temperature. The irradiated mixture was submitted to silica gel column chromatography eluting with chloroform-ethyl acetate (5:1) to give 3 (0.154 g; yield 40 %), m.p. 276-277°C; IR (KBr), 3340, 1715, 1610, 760 cm^{-1} ; $^1\text{H-NMR}$ (DMSO), δ 3.25 (s, 6H, 2 N-Me), 5.90 (s, 1H, C-H), 7.00-7.50 ppm (m, 13H, 11 aromatic and olefinic H, N-H); MS, m/z 384 (M^+), 267, 182. Anal. Calcd. for $\text{C}_{23}\text{H}_{20}\text{N}_4\text{O}_2$: C, 71.87; H, 5.21; N, 14.58. Found: C, 71.90; H, 5.19; N, 14.50.

Time course of the solid-state photoreaction.

The mixed crystal of 1 and 2 (1:4 molar ratio) was irradiated as above and an aliquot was taken time to time and analyzed by HPLC: column, MCH C_{18} reversed phase;

mobile phase, water/methanol (40 : 60); detected at 254 nm. The result is shown in Figure 2.

Photochemical reaction of 1 with 2 in solution.

A solution of 1 (0.168 g, 0.1 mmol) and 2 (0.351 g, 0.3 mmol) in 150 ml of acetonitrile was irradiated with a 300 W high-pressure mercury lamp (Pyrex housing) for 15 h under bubbling nitrogen. After the removal of the solvent in reduced pressure, the residue was submitted to column chromatography (Qing Dao 300 silica gel and elution with 5 : 1 chloroform-ethyl acetate) to give 1,3-dimethyluracil 4 in 20 % yield. When methanol was used as the solvent, 4 was obtained in 65 % yield.

X-ray crystallography.

A colorless crystal of 5-(bis-1-indolyl)methyl-1,3-dimethyluracil (3), $C_{23}H_{20}N_4O_2$, having approximate dimensions of 0.3 x 0.3 x 0.3 mm was mounted on a glass fiber in a random orientation. Preliminary examination and data collection were performed with Mo $K\alpha$ radiation ($\lambda = 0.71073$ Å) on an ENRAF-NONIUS CAD4 diffractometer equipped with a graphite crystal incident beam monochromator. A total of 3804 independent reflections were collected in the range of $2 < \theta < 25^\circ$ by ω - 2θ scan technique at room temperature, in which 1722 reflections with $I > 3\sigma(I)$ were considered to be observed and used in the succeeding refinement. The corrections for LP factors and for absorption based on a series of ψ scan were applied to the data.

The crystal is monoclinic, space group $P2_1/n$, with $a = 10.831(1)$, $b = 9.650(2)$, $c = 19.355(2)$ Å, $\beta = 102.65(1)^\circ$, $V = 1973.8$ Å³, $M_r = 384.44$, $Z = 4$, $D_x = 1.29$ g/cm³, $\mu = 0.80$ cm⁻¹, $F(000) = 808$.

The structure was solved by direct method (MULTAN82). The most of non-hydrogen atoms were located from an E-map. The coordinates of remaining non-hydrogen atoms and hydrogen atoms were found in the succeeding difference Fourier synthesis. The final refinement by full matrix least-square method with anisotropic thermal parameters for non-hydrogen atoms and isotropic thermal parameters for hydrogen atoms was converged with unweighted and weighted agreement factors of 0.052 and 0.051. All calculations were performed on a PDP11/44 computer using SDP-PLUS program system.

References

1. Fox, M. A. (Editor) Organic Phototransformations in Non-homogeneous Media, American Chemical Society, Washington, D. C., 1985.
2. Ramamurthy, V. Tetrahedron **1986**, *42*, 5753.
3. Scheffer, J. (Editor) Organic Photochemistry in Organized Media (Tetrahedron Symposia-in-Print No. 211 Tetrahedron **1987**, *43*, No. 7.
4. Anpo, M.; Matsuura, T. (editors) Photochemistry on Solid Surfaces; Elsevier Science Publishers B. V.; Amsterdam, 1989.
5. Ito, Y.; Meng, J.-B.; Suzuki, S.; Kusunaga, Y.; Matsuura, T. Tetrahedron Lett. **1985**, *26*, 2093.
6. Matsuura, T.; Meng, J.-B.; Ito, Y.; Irie, M.; Fukuyama, K. Tetrahedron **1988**, *43*, 2451.
7. Meng, J.-B.; Ito, Y.; Matsuura, T. Tetrahedron Lett. **1987**, *28*, 6665.
8. Ito, Y.; Matsuura, T.; Tabata, K.; Meng, J.-B.; Fukuyama, K.; Sasaki, M.; Okada, S. Tetrahedron **1987**, *43*, 1307.
9. Ito, Y.; Matsuura, T.; Fukuyama, K. Tetrahedron Lett. **1988**, *29*, 3087.
10. Ito, Y.; Ito, H.; Ino, M.; Matsuura, T. Tetrahedron Lett. **1988**, *29*, 3091.
11. Ito, Y.; Ref. 4., p. 469.
12. Ito, Y.; Matsuura, T. J. Photochem. Photobiol. A: Chemistry **1989**, *50*, 141.
13. Meng, J.-B.; Fu, D.-C.; Yao, X.-K.; Wang, R.-J.; Matsuura, T. Tetrahedron, in the press.
14. See ref. 7 and literatures cited therein.
15. Julian, D. R.; Tringham, G. D. J. C. S. Chem. Commun. **1973**, 13.
16. Wang, S. Y.; Photochem. Photobiol. **1965**, *4*, 473.