

MULTIPLE PATHS FOR PHOTOALKYLATION OF PYRIDINECARBOXYLIC ESTERS
IN ALCOHOLS

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Photochemical substitution of ring hydrogen of pyridinecarboxylic esters by alkyl groups derived from solvent alcohols occurs in several paths: 1) alkylation initiated by the excited carbonyl moiety of the ester group and 2) alkylation initiated by the excitation of the π -electronic system of the pyridine ring. In the photoreaction of methyl 3-pyridinecarboxylate in acidic methanol, three types of excited state (two triplet states for alkylation and a singlet state for alkoxylation) contribute simultaneously.

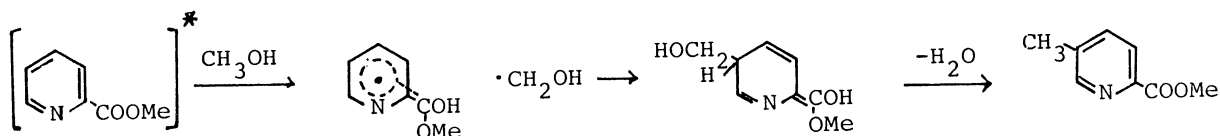
Photochemical reactions of N-heteroaromatic compounds with alcohols have been investigated.¹⁾ Previously we reported alkylation and alkoxylation in the photoreactions of pyridinecarboxylic acid derivatives.²⁾ Stermitz et al. explained the photoalkylation at α - and γ -positions in the mechanism initiated by the hydrogen abstraction by the excited protonated pyridine derivatives from alcohol.³⁾ Castellano et al. proposed the mechanism for the photoalkylation of pyridine derivatives via biphotonic electron transfer in alcoholic solutions acidified with HCl.⁴⁾ We report here that the photoalkylation of 2- and 3-pyridinecarboxylic esters proceeds in several different pathways depending on the structure of the esters and on the reaction conditions.

The photoalkylation of methyl 2-pyridinecarboxylate(1) in methanol is dependent on the added acid as is shown in Table 1.

Table 1. Photoreactions of methyl 2-pyridinecarboxylate(1) in methanol
[1] = 10^{-3} mol dm⁻³, [H₂SO₄] = 5×10^{-2} mol dm⁻³

		Yield of product/%		
Added acid	Irr. time min	 (<u>2</u>)	 (<u>3</u>)	 (<u>4</u>)
—	60	15	—	—
H ₂ SO ₄	10	—	5	88

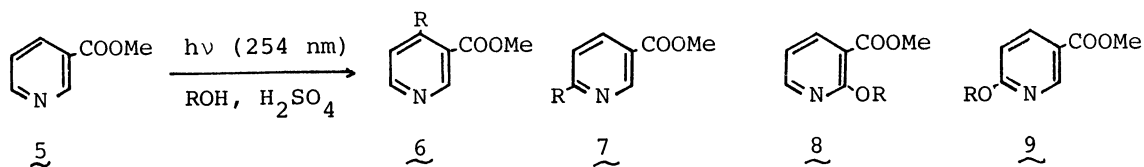
photoreaction normally occurs at α - and β -positions in pyridine derivatives.¹⁾ In the present system the β -position is substituted in the absence of acid. For the unusual alkylation at β -position the participation of the ester group should be taken into consideration. The hydrogen abstraction by the excited carbonyl from alcohol⁵⁾ can explain the photoalkylation at the β -position.



In the presence of sulfuric acid, alkylation, being a minor reaction, occurs exclusively at γ -position as explained by the mechanism of Stermitz et al..³⁾

The observed change in the position of photoalkylation is correlated with the electronic states calculated by means of CNDO/2.⁶⁾ The HOMO of the free base of 1 is assigned to the non-bonding electrons at C=O, while that of protonated 1 is assigned to π -electrons of the pyridine ring (Fig. 1).

The acidity dependence of the photoreactions of 3-pyridinecarboxylic esters in the presence of sulfuric acid is complex, photoalkylation and photoalkoxylation competing (Fig. 2).



The region where photoalkylation is effective is divided into two parts. In the higher acidity region, alkylation and alkoxylation are comparable.

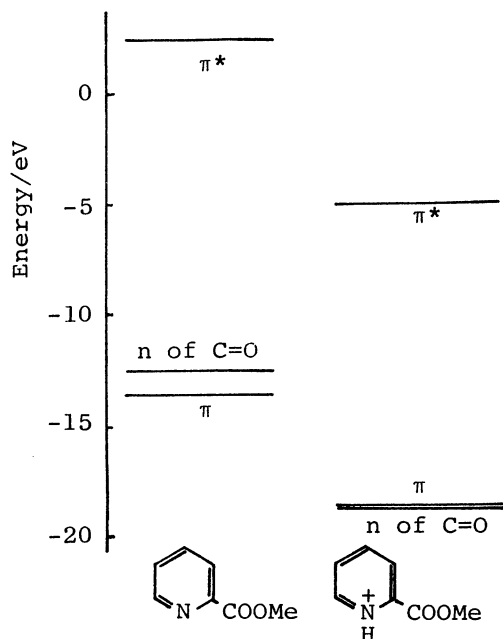


Fig. 1. Electronic state of 1.

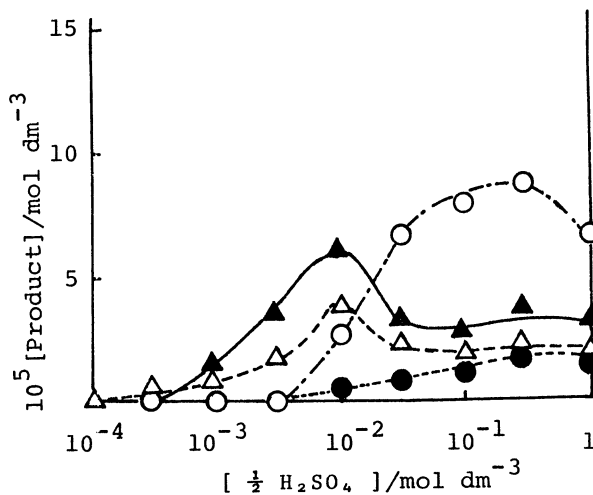


Fig. 2. Dependence of the photoreaction of 5 on the acid concentration. R = Me
[5] = 10^{-2} mol dm⁻³,
Irr. time, 60 min
--- Δ --- 6, --- \blacktriangle --- 7, --- \circ --- 8, --- \bullet --- 9

The effects of benzene, naphthalene, and oxygen are different for alkylation and alkoxylation (Table 2). The effect of anthracene, a triplet quencher ($E_T = 42$ kcal/mol), show that the alkylation and the alkoxylation originate from triplet and singlet excited states, respectively. Furthermore, the different dependence of anthracene on the two alkylation reactions suggests that the products alkylated at α - and γ -positions originate from excited states of different character. This view is supported by the temperature dependence of the photoreactions. Figure 4 is the plot of $\ln(\text{relative yield})$ vs. the reciprocal of temperature, and the slope

Table 2. Effects of additives on the photoalkylation and alkoxylation of 5
 $[5] = 10^{-2} \text{ mol dm}^{-3}$; Irradiation time, 50 min

Additive	$\frac{[\text{Additive}]}{\text{mol dm}^{-3}}$	$[\text{H}_2\text{SO}_4] = 5 \times 10^{-3} \text{ mol dm}^{-3}$				$[\text{H}_2\text{SO}_4] = 5 \times 10^{-2} \text{ mol dm}^{-3}$			
		$10^5 [\text{Product}]/\text{mol dm}^{-3}$				$10^5 [\text{Product}]/\text{mol dm}^{-3}$			
		<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>
—	—	3.7	6.1	2.7	0.5	1.8	2.7	7.9	1.1
Benzene	10^{-1}	1.6	3.3	0.0	0.0	3.1	5.8	6.6	1.1
Naphthalene	10^{-2}	0.9	5.4	0.0	0.0	2.7	9.3	6.6	0.5
Oxygen	—	0.0	0.0	1.4	0.5	0.0	0.0	1.4	0.5

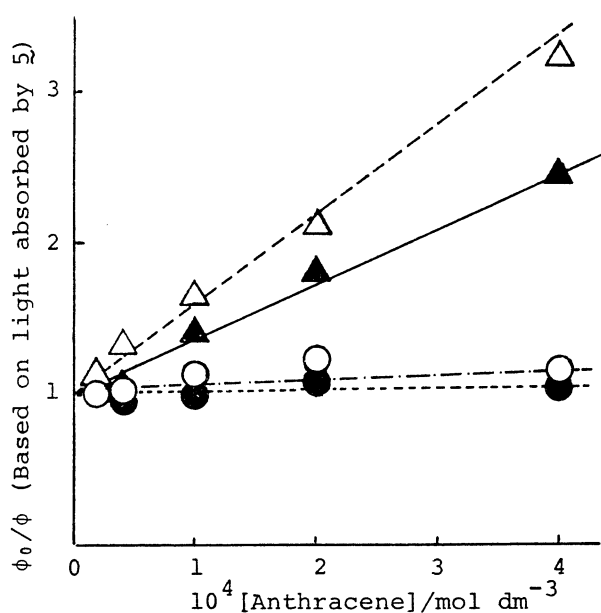


Fig. 3. Effect of anthracene(10) on photoreactions of methyl 3-pyridinecarboxylate(5)
 $[5] = 10^{-2} \text{ mol dm}^{-3}$, $[\text{H}_2\text{SO}_4] = 5 \times 10^{-2} \text{ mol dm}^{-3}$
 $\phi_0/\phi = Y/L$, $\gamma = \frac{\text{Yield in the absence of } 10}{\text{Yield in the presence of } 10}$
 $L = \frac{\text{Light absorbed by } 5 \text{ and } 10}{\text{Light absorbed by } 5}$
 -- Δ -- 6, -- \blacktriangle -- 7, -- \circ -- 8, -- \bullet -- 9

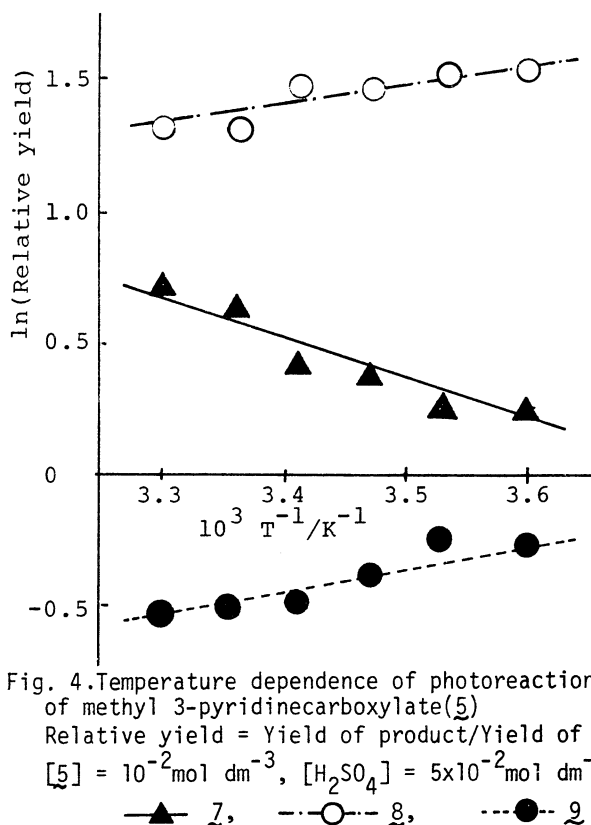


Fig. 4. Temperature dependence of photoreactions of methyl 3-pyridinecarboxylate(5)
 Relative yield = Yield of product/Yield of 6
 $[5] = 10^{-2} \text{ mol dm}^{-3}$, $[\text{H}_2\text{SO}_4] = 5 \times 10^{-2} \text{ mol dm}^{-3}$
 -- \blacktriangle -- 7, -- \circ -- 8, -- \bullet -- 9

of the plot is the difference in the activation energies between a given reaction and the standard reaction (in this case the formation of 6). The plots for the two alkoxylation reactions have the same temperature dependence, whereas the photoalkylation at the α - and γ -position differs in temperature dependence. The result in an ethanol solution is compared with that in a methanol solution (Table 3). The irradiation in ethanol depresses the alkoxylation, but the change in the ratio of the isomers is small. Alkylation becomes dominant and 7 is selectively formed. This fact also supports the hypothesis that the alkylation reactions at the α - and γ -positions are due to the different excited states. These two triplet states may be assigned to the $n-\pi^*$ of C=O and $\pi-\pi^*$ of pyridine ring.

This is a rare example of the photoreactions that involve three types of excited state (two triplet states for alkylation and a singlet for alkoxylation) simultaneously.

Table 3. Dependence of photoreactions of 5 on alcohol

$$[\text{5}] = 2 \times 10^{-2} \text{ mol dm}^{-3}$$

$$[\text{H}_2\text{SO}_4] = 1.5 \times 10^{-1} \text{ mol dm}^{-3}$$

Alcohol	Yield of product/%			
	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>
MeOH	7.1	9.5	8.8	3.8
EtOH	0.0	31.6	2.0	0.7

References and Notes

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- 5) Photochemical hydrogen abstraction by ester C=O has been reported for some aromatic esters; K.Fukui, K.Senda, Y.Shigemitsu, and Y.Odaira, J. Org. Chem., 37, 3176 (1972).
- 6) Electronic states of methyl 2-pyridinecarboxylate were calculated using the CNDO/2 program (Q.C.P.E. 141) prepared by Pople, Beveridge, and Dobosh and arranged by Kihara, Fujikawa, and Aoyama.

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