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THE $S_{RN}2$ MECHANISM OF NUCLEOPHILIC SUBSTITUTION[1]

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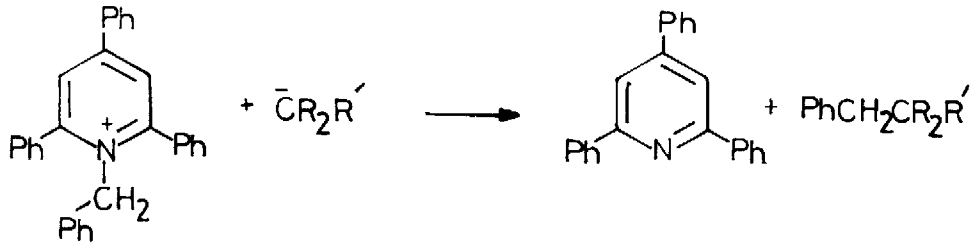
Summary: 1-Alkylpyridiniums react with nitroalkane and ethylmalonate anions by a radical nucleophilic substitution mechanism not involving radical chains.

Radical chain nucleophilic displacements were first recognised in 1970,[2] and have since been shown to be of widespread occurrence.[3] Bunnett[2] designated such displacements of aryl iodides by soft anionic nucleophiles as $S_{RN}1$ on the basis of the unimolecular dissociation, for example, $ArI^{-\cdot} \rightarrow Ar^{\cdot} + I^{-}$.

We previously reported[1] that 1-alkyl-2,4,6-triphenylpyridiniums C-alkylate nitroalkane anions and we now believe that this is the first example of a general class of radical nucleophilic displacements which we designate $S_{RN}2$, to distinguish them from the radical chain mechanisms $S_{RN}1$. Thus, we now find that the hindered diethyl ethylmalonate carbanion (2b) is C-benzylated in high yield by 1-benzyl-2,4,6-triphenylpyridiniums (1) in refluxing toluene in average 69% yield for 4 examples (benzyl 84%, 2-chlorobenzyl 63%, 4-chlorobenzyl 57%, and 4-methylbenzyl 72%). The reaction proceeds already at 25°, but at this temperature long periods of stirring are needed because of the poor solubility of the anion.



1 2 3 4

a: R = Me, R′ = NO_2 b: R = CO_2Et, R′ = Et c: R = H, R′ = NO_2

For kinetic and mechanistic studies, reactions were followed spectrophotometrically.^{4} In the presence of a large excess of 2-nitropropane anion (2a) (pseudo-unimolecular conditions) in dmso solution at 30°, 1-benzyl-2,4,6-triphenylpyridinium (1) gave 2,4,6-triphenylpyridine (3) and 1-phenyl-2-methyl-2-nitromethane (4a) in a clean second order process [cf. eqn (1)] (cf. Fig 1) (k_2 = 4.45 1 mole^{-1} s^{-1}) as shown by the disappearance of the absorption of 1 at 312 nm.

$$d[3]/dt = k_2\,[1]\,[2] \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

In marked contrast, the reaction of diethyl ethylmalonate anion (2b) with 1-benzyl 2,4,6-triphenylpyridinium in toluene at 25° showed an initial rapid loss of the pyridinium peak observed at 305 nm with simultaneous appearance of absorbance at 350 nm (extinction coefficient $\not>$ 5000). Subsequently, the peak due to 2,4,6-triphenylpyridine (3) (λ 304 nm) appeared gradually, following first order kinetics with k_1 = 1.77 x 10^{-3} s^{-1} [eqn (2)].

$$d[3]/dt = k_1\,[\mathrm{CTC}] \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

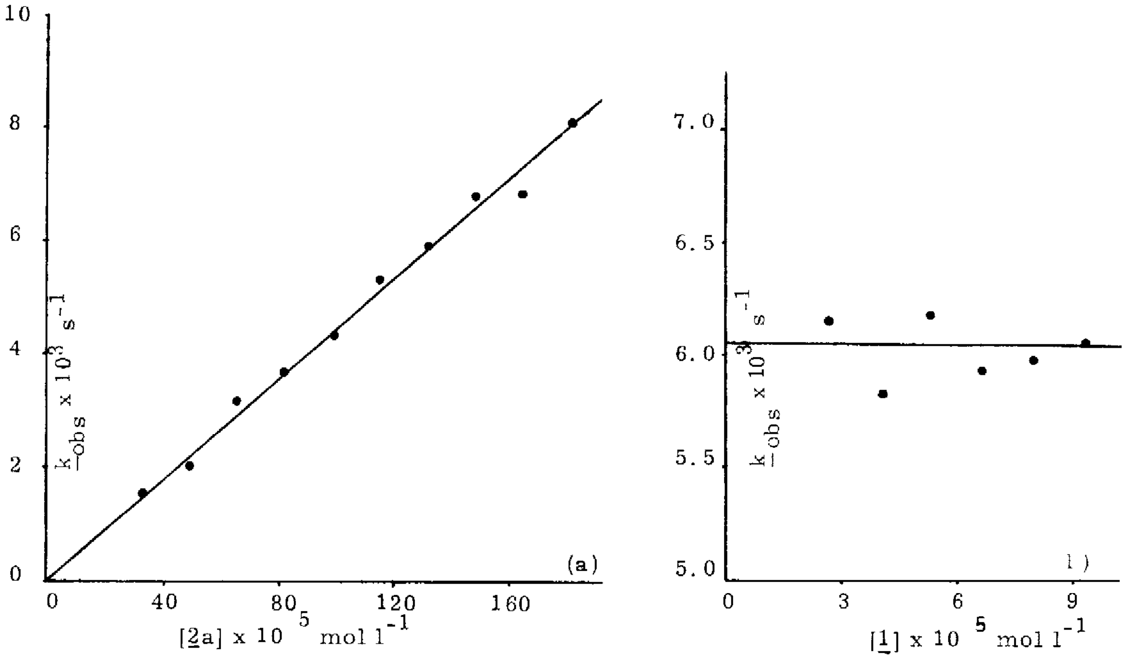


FIGURE 1 Dependence of k_{obs} x 10^{3} s^{-1} for the reaction of 1 with 2a (under pseudo-unimolecular conditions - large excess of 2a) in dmso at 30° on (a) the concentration of 2a (keeping [1] at 6.60 x 10^{-5} mole 1^{-1}) and (b) the concentration of 1 (keeping [2a] at 1.32 x 10^{-3} mole 1^{-1}).

Pyridiniums are expected to give charge-transfer complexes (CTC) with soft nucleophiles,[5] and Kosower[6] has also demonstrated the ease of electron-transfer processes interconverting pyridiniums and pyridinyls. The above kinetic results are explained by the mechanism of eqns (3) and (4). For the 2-nitropropane anion reaction in dmso step 2 (eqn 4) is fast and eqn (3) is rate determining. By contrast, for the malonate anion $\underline{2}$b in toluene, the charge transfer complex (CTC) appears to be almost completely formed in a fast step, which is followed by rate determining dissociation of eqn (4).

$$\underline{1}^{+} + \underline{2}^{-} \rightleftharpoons \text{CTC} \qquad (3)$$

$$\text{CTC} \longrightarrow \underline{3} + \underline{4} \qquad (4)$$

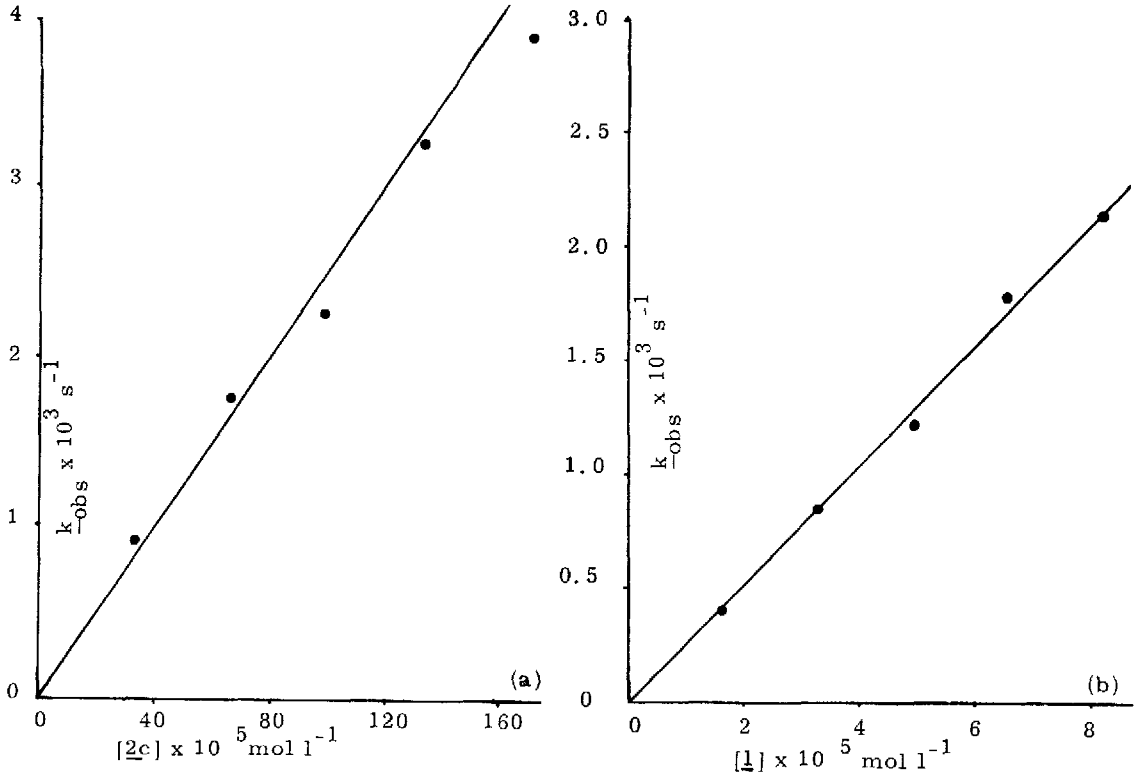


FIGURE 2 Dependence of $\underline{k}_{obs}$ for the reaction of $\underline{1}$ with $\underline{2}$c (under pseudounimolecular conditions - large excess of $\underline{2}$c) in pentanol at 25° on (a) the concentration of $\underline{2}$c (keeping [$\underline{1}$] at 6.60 x 10^{-5} mole l^{-1}) and (b) the concentration of $\underline{1}$ (keeping [$\underline{2}$c] at 1.32 x 10^{-3} mole l^{-1}).

The reaction with nitromethane anion (2c) in pentanol (this under preparative conditions forms 2-phenylnitroethane)[1] was much slower; it was followed at 25°, and was found to be third order according to eqn (5), (cf. Fig 2), with k_3 = 3.48 x 10^4 1^2 mole^{-2} s^{-1}. This result suggests that the collapse of the CTC to 3 and 4 may involve the mechanism of eqns (6) - (8).

$$d[\underline{3}]/dt = \underline{k}_3\ [\underline{1}]^2\ [\underline{2}c] \qquad (5)$$

$$\text{CTC} \rightleftharpoons \underline{1}^{\cdot} + \underline{2}^{\cdot} \qquad (6)$$

$$\underline{2}^{\cdot} + \underline{1}^{+} \longrightarrow \underline{4} + \underline{3}^{\cdot +} \qquad (7)$$

$$\underline{3}^{\cdot +} + \underline{1}^{\cdot} \longrightarrow \underline{1}^{+} + \underline{3} \qquad (8)$$

For the reaction for nitromethane anion in pentanol, step 2 [eqn (7)] is rate-determining with step 1 [eqn (6)] a preequilibrium and step 3 [eqn (8)] fast. Intermediates such as $\underline{1}^{\cdot}$ and $\underline{2}^{\cdot}$ are not unlikely considering the work of Kosower on the interaction of pyridinyls with nitrobenzylhalides.[6] Russell et al[7] have recently shown that the reaction of N-(p-nitrobenzyl)pyridinium with 2-nitropropane anion involves electron transfer processes, cf. Kornblum work.[3b] Reaction of 2c with 1 in dmso parallels the results of 2b with 1: CTC is rapidly formed and then slowly collapses to 3 following 1st order kinetics.[8]

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(4) Kinetics were followed spectrophotometrically at 312 nm (disappearance of 1 in dmso and pentanol) and 304 nm (appearance of 3 in toluene).

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(8) Addition of m-dinitrobenzene to the reaction of 2a with 1 in dmso solution at 30 °C had little effect on the observed $\underline{k}_2$ rate constant (reduction in rate of $\ngtr$ 15%). This provides additional evidence against an $S_{RN}1$ radical chain mechanism.[7]

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