Table IV. Influence of Electron Acceptors on the Reaction of the Sodium Salt of I with *p*-Nitrobenzyl Chloride[a]

Acceptor (moles/mole of I)	% yield C-Alkylate	% yield O-Alkylate	$t_{1/2}$,[b] hr
None	90	2	0.5
C_6Cl_6 (2)	67	24	2
$C_6H_5NO_2$ (2)	67	26	3
m-DNB (2)	58	36	3
p-DNB (0.1)	47	42	4
p-DNB (1)	46	49	6
p-DNB (2)	44	46	7

[a] At room temperature; 0.1 *M* in sodium salt of I and in halide. [b] Time required for the reaction to go 50% to completion.

alkylate falls to 44% and that of the oxygen alkylate rises to 46%; this is essentially the product distribution obtained with benzyl and *m*-nitrobenzyl chlorides (Table I). Thus, by intercepting the radical-anion intermediate, *p*-DNB blocks the radical-anion reaction of I with *p*-nitrobenzyl chloride while allowing the SN2 process to continue unchecked. In other words, *p*-DNB increases the proportion of oxygen alkylate by retarding carbon alkylation rather than by facilitating oxygen alkylation. As would be predicted from this view, the rate of reaction of I with *p*-nitrobenzyl chloride is reduced when electron acceptors are present, and the decrease is greatest with *p*-DNB (*cf.* Table IV).

Finally, in contrast to the effect which *p*-DNB has on the reaction of I with *p*-nitrobenzyl chloride, the addition of *p*-DNB to reactions employing benzyl chloride, *m*-nitrobenzyl chloride and bromide, and *p*-nitrobenzyl bromide and iodide is without effect on the product distribution or the rate of these reactions. All these facts are consonant with the proposal that alkylation of I by the various benzylic halides listed in Table I is an SN2 process, except in the case of *p*-nitrobenzyl chloride.

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(4) National Institutes of Health Predoctoral Fellow, 1963–1965.

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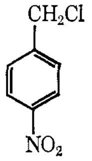
Chain Reactions in Substitution Processes Which Proceed *via* Radical-Anion Intermediates

Sir:

Good grounds exist for considering the alkylation of various anions by *o*- and *p*-nitrobenzylic chlorides, (*e.g.*, II and III) to be radical-anion processes.[1] In this communication we present evidence for the view that these radical-anion substitutions are chain reactions.[2]


II

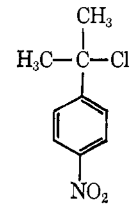

III

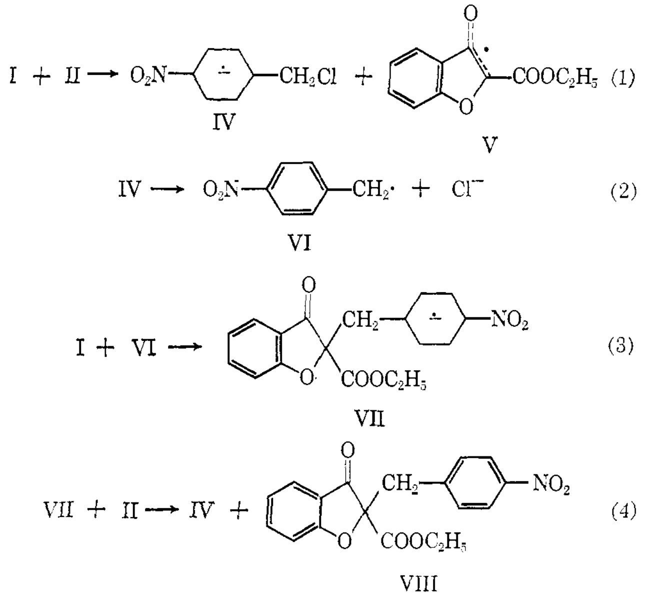
Table I summarizes the effect of cupric salts on the reaction between the sodium salt of 2-carbethoxycoumaran-3-one (I)[1c] and *p*-nitrobenzyl chloride. The consequences of adding 6×10^{-6} mole of cupric chloride/mole of I are particularly striking; the product distribution is changed from 90% C- and 2% O-alkylate to 45% C- and 48% O-alkylate and the second-order rate constant falls from 3×10^{-3} to 5×10^{-5}. Significantly, the product distribution and the rate constant in the presence of this amount of cupric chloride are not very different from that obtained on treating *m*-nitrobenzyl chloride with I; 40% C-, 52% O-, $k = 1.9 \times 10^{-5}\ M^{-1}\ \text{sec}^{-1}$.[1c] Thus, cupric chloride, although present in only $^1/_{160,000}$ the concentration of *p*-nitrobenzyl chloride and I, is able to suppress the radical-anion reaction while allowing the SN2 displacement process[1c] to proceed unchecked. It seems probable then that the reaction of *p*-nitrobenzyl chloride with I is a chain process, and the mechanism in Scheme I is proposed.

Table I. The Effect of Cupric Salts on the Product Distribution and Rate of Reaction of the Sodium Salt of 2-Carbethoxycoumaran-3-one (I) with *p*-Nitrobenzyl Chloride[a]

Added salt	Moles of salt/ mole of I	% yield C-Alkylate	% yield O-Alkylate	$k \times 10^5$, M^{-1} sec^{-1}
None		90	2	300
$CuCl_2$	6×10^{-4}	44	50	
$CuCl_2$	3×10^{-4}	38	53	6
$CuCl_2$	6×10^{-6}	40[b]	60[b]	2
$CuCl_2$	6×10^{-6}	45[c]	48[c]	5[c]
$CuSO_4$	6×10^{-6}	88[b]	12[b]	
$CuSO_4$	6×10^{-6}	76[c]	15[c]	

[a] At 0° in DMF; both I and the *p*-nitrobenzyl chloride are 0.10 *M*. [b] By nmr. [c] In a Teflon bottle; the rate and product distribution of the uninhibited reaction was the same in glass and in Teflon.

Scheme I



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(1) (a) R. C. Kerber, G. W. Urry, and N. Kornblum, *J. Am. Chem. Soc.*, 87, 4520 (1965); (b) N. Kornblum, T. M. Davies, G. W. Earl, N. L. Holy, R. C. Kerber, M. T. Musser, and D. H. Snow, unpublished work; (c) N. Kornblum, R. E. Michel, and R. C. Kerber, *J. Am. Chem. Soc.*, 88, 5660 (1966).

(2) Dr. Russell has independently reached the same conclusion on different grounds regarding the 2-nitro-2-propyl anion; *cf.* G. A. Russell and W. C. Danen, *ibid.*, 88, 5663 (1966).

Steps 1 and 2 are strictly analogous to those proposed for the carbon alkylation of nitroparaffin salts by *p*-nitrobenzyl chloride.[1a] Step 3, combination of the *p*-nitrobenzyl radical with the β-keto ester anion I to give the radical anion of the carbon alkylate VII, is the key reaction of the chain sequence. There is no precedent for a reaction of this type, although analogous couplings of radicals and anions to produce radical anions have been suggested.[3] The intrinsic reasonableness of step 3 becomes apparent when the various resonance forms contributing to the *p*-nitrobenzyl radical are considered;[1a] one sees then that step 3 resembles the Michael addition of anion I to a conjugated nitroolefin.

Step 4, the transfer of an electron from a nitroaromatic radical anion VII to a nitroaromatic II, is a well-documented process and is often very rapid.[4] The products of step 4 are the carbon alkylate of anion I and the radical anion of *p*-nitrobenzyl chloride; the latter perpetuates the chain by undergoing step 2.

It is apparent from Table I that cupric chloride is a far better suppressor of carbon alkylation than is cupric sulfate. Furthermore, cupric chloride retards the rate of reaction to a much greater extent than cupric sulfate; it is of interest that with cupric sulfate the second-order rate constant shows a pronounced decrease with time, leveling off at about the same value of k as for the reaction conducted in the presence of cupric chloride (Figure 1). Presumably this is because chloride ions liberated by the reaction of I with *p*-nitrobenzyl chloride convert cupric sulfate to cupric chloride.[5]

The proposed chain mechanism provides a simple basis for understanding this disparity in the ability of cupric chloride and cupric sulfate to affect the reaction of I with *p*-nitrobenzyl chloride. Kochi and Mog[6] have shown that, although the radical $(CH_3)_2\dot{C}CN$ is readily oxidized by ligand transfer when exposed to cupric chloride, it is inert to oxidation by electron transfer. In the same way, with the *p*-nitrobenzyl radical VI, ligand-transfer oxidation by cupric chloride (eq 5) should be facile whereas electron-transfer oxidation to the *p*-nitrobenzyl carbonium ion by cupric sulfate (eq 6) should not take place readily. Thus, the fact that traces of cupric chloride are so very effective in suppressing carbon alkylation, whereas cupric sulfate is ineffective, supports the view that carbon alkylation is a chain process involving *p*-nitrobenzyl radicals.[7]

$$\text{VI} + CuCl_2 \longrightarrow \text{II} + CuCl \qquad (5)$$

(6)

$$\text{VI} + CuSO_4 \longrightarrow O_2N-C_6H_4-\overset{+}{C}H_2 \qquad (6)$$

Much less than a stoichiometric amount of *p*-dinitrobenzene (*p*-DNB) is able to suppress carbon alkylation of I.[1c] Furthermore, the order of effectiveness of nitroaromatics in suppressing the carbon alkylation of I is *p*-DNB > *m*-DNB > nitrobenzene, an order identical with their ease of reduction.[1a] These facts become readily intelligible on the basis of the chain sequence of eq 1–4: nitroaromatics interrupt the chain reaction by taking an electron away from the chain carrying radical anions IV and VII. A completely analogous chain sequence serves to explain why much less than a stoichiometric amount of *p*-DNB stops carbon alkylation of the salts of 2-nitropropane.[1a]

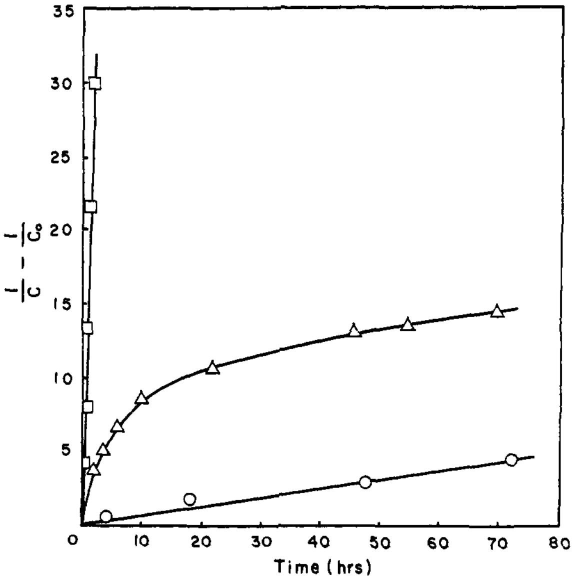

Figure 1. The influence of cupric salts on the rate of reaction of I with *p*-nitrobenzyl chloride in DMF at 0° (both reactants at 0.10 *M*): □, nothing added; △, 6 × 10^{-7} *M* in $CuSO_4$; ○, 6 × 10^{-7} *M* in $CuCl_2$.

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[3] N. Kornblum, cited by H. Feuer, *Tetrahedron Suppl.*, 1, 107 (1964); E. E. van Tamelen, J. I. Brauman, and L. E. Ellis, *J. Am. Chem. Soc.*, 87, 4964 (1965); Russell and Danen, ref 2.

[4] *Cf.* footnote 16 in ref 1a.

[5] An initially colorless solution of cupric sulfate in DMF (0.003 *M*) takes on the characteristic yellow color of cupric chloride dissolved in DMF when sodium chloride is added.

[6] J. K. Kochi and D. M. Mog, *J. Am. Chem. Soc.*, 87, 522 (1965).

[7] If it is assumed that cupric chloride is much more easily reduced than cupric sulfate, then suppression of carbon alkylation can be explained as a consequense of facile one-electron transfer to cupric chloride by the chain carrying radical anions IV or VII.

[8] National Institutes of Health Predoctoral Fellow, 1963–1965.

Coupling Reactions of the 2-Nitro-2-propyl Anion[1]

Sir:

The uniqueness of the reaction of the 2-nitro-2-propyl anion with *p*-nitrobenzyl chloride is well recognized.[2,3] Kerber, Urry, and Kornblum concluded that the reaction involved electron transfer with formation of an intermediate radical anion followed by selective coupling of the 2-nitro-2-propyl and *p*-nitrobenzyl radicals.[3] We conclude that this reaction is a *chain process* involving the attack of the *p*-nitrobenzyl radical upon the 2-nitro-2-propyl anion.

$$R^- + R'X \xrightarrow{h\nu} R\cdot + R'X\cdot^- \qquad (1)$$

$$R'X\cdot^- \longrightarrow R'\cdot + X^- \qquad (2)$$

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[1] Electron Transfer Processes. V.

[2] L. Weisler and R. W. Helmkamp, *J. Am. Chem. Soc.*, 67, 1167 (1945); H. B. Hass, E. J. Berry, and M. L. Bender, *ibid.*, 71, 2290 (1949); H. B. Hass and M. L. Bender, *ibid.*, 71, 1767, 3482 (1949).

[3] R. C. Kerber, G. W. Urry, and N. Kornblum, *ibid.*, 87, 4520 (1965).