Tetrahedron Letters No.40, pp. 3607-3612, 1965. Pergamon Press Ltd.
Printed in Great Britain.

ON THE STEREOCHEMISTRY OF ION-PAIR RETURN ASSOCIATED WITH SOLVOLYSIS OF 2-PHENYL-2-BUTYL p-NITROBENZOATE

Harlan L. Goering and Sherwood Chang[1]
Department of Chemistry, University of Wisconsin
Madison, Wisconsin

(Received 13 July 1965; in revised form 16 August 1965)

Ion-pair return associated with solvolysis (alkyl-oxygen cleavage) of optically active benzhydryl[2] and α-phenylethyl[3] p-nitrobenzoates (reaction 1) results in randomization of the ester carboxyl oxygen atoms (reaction 2) and racemization of the unsolvolyzed substrate (reaction 3). These transformations are first order and the last two are intramolecular.[2,4]

$$ROCOC_6H_4NO_2 \xrightarrow{k_t} ROH + HOCOC_6H_4NO_2 \qquad (1)$$

$$ROC^*OC_6H_4NO_2 \xrightarrow{k_{eq}} R^*OC^*OC_6H_4NO_2 \qquad (2)$$

$$(\underline{d} \text{ or } \underline{l})\text{-}ROCOC_6H_4NO_2 \xrightarrow{k_{rac}} (\underline{dl})\text{-}ROCOC_6H_4NO_2 \qquad (3)$$

Indications that k_{eq} corresponds to total ion pair return have been presented elsewhere.[5] Thus, evidently $k_{eq} + k_t$ is the rate constant for total ionization and k_{eq}/k_t is the ratio of ion-pair return to solvolysis. Racemization associated with return is measured by k_{rac}; the rest of the return ($k_{eq} - k_{rac}$) proceeds with preservation of configuration.

$$\begin{tikzcd}
ROCOC_6H_4NO_2 \arrow[r, shift left, "k_{eq} + k_t"] & \text{ION PAIR INTERMEDIATE(S)} \arrow[l, shift left, "k_1"] \arrow[d, "k_2"] \\
 & \text{PRODUCTS}
\end{tikzcd}$$

We reported recently[2] that ion-pair return associated with solvolysis of *p*-chlorobenzhydryl *p*-nitrobenzoate results in substantial racemization. For example, in 90% acetone at 100°, k_{eq}/k_t (equivalent to k_1/k_2) = 2.5 and k_{rac}/k_{eq} = 0.38; *i.e.*, return results in 38% racemization. Similar results have been observed for solvolysis of *p*-methylbenzhydryl (k_{eq}/k_t = 3.2; k_{rac}/k_{eq} = 0.37) and α-anisylethyl *p*-nitrobenzoate (k_{eq}/k_t = 2.2; k_{rac}/k_{eq} = 0.53) in 90% acetone at 80°.[6]

We now report the first example in which the stereochemistry of ion pair return (*i.e.*, % racemization) has been determined for a tertiary system in which the anion returns to the original carbon atom. In this work polarimetric (k_α), titrimetric (k_t) and oxygen-equilibration (k_{eq}) first-order rate constants have been determined[2] for solvolysis of 2-phenyl-2-butyl *p*-nitrobenzoate (I) in 80% and 90% aqueous acetone. Solvolysis products have also been examined and relative configurations (and optical purities) of reactant and product established.

The pertinent kinetic data are presented in Table I. In all cases excellent first-order behavior was observed and rate constants were reproducible. (+)-2-Phenyl-2-butyl p-nitrobenzoate,[*] $[\alpha]_D^{24.5}$ + 56.7° (80% acetone), +57.9° (CH_2Cl_2), derived from active alcohol,[7] was used in the polarimetric experiments and product studies. The (+)-ester was related to (-)-alcohol, $[\alpha]_D^{24.5}$ -13.8° (CH_2Cl_2), by reduction with $LiAlH_4$. Values of k_{eq} for ether-O^{18}- and carbonyl-O^{18}-labeled ester were indistinguishable and total O^{18}-contents remained constant throughout the reaction.

TABLE I

Rate Constants for Solvolysis (k_t), Oxygen Equilibration (k_{eq}) and Change of Optical Activity (k_α) Associated with Solvolysis of 2-Phenyl-2-butyl p-Nitrobenzoate at 78.6°[a]

Rate Constant[b]	90% Acetone[c] 10^2 hr.$^{-1}$	80% Acetone[c] 10^2 hr.$^{-1}$
k_α	1.013 ± 0.003	8.59 ± 0.04
k_t	0.967 ± 0.001	8.19 ± 0.03
k_{eq}	0.581 ± 0.007[d]	4.00 ± 0.08[e]
k_{rac}[f]	0.046 ± 0.019	0.40 ± 0.17

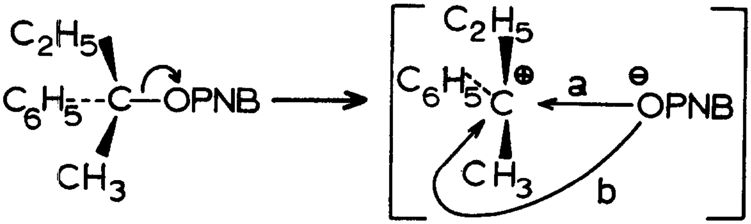
a) Initial concentrations were about 0.03 M. b) Average (and average deviation) of constants for two independent kinetic experiments. c) Compositions based on volumes of pure components at 25° prior to mixing. Solvent from the same batch was used for all of the determinations. d) Average (and average deviation) of three integrated constants for a single kinetic experiment. e) Initial concentrations 0.04 and 0.06 M. f) Equal to $k_\alpha - k_t$;[3] uncertainties estimated from limiting values of k_α and k_t.

These data provide significant information concerning the chemical and stereochemical behavior of the ion-pair

---

[*] Satisfactory elemental analysis obtained for racemic and optically active ester.

intermediate(s) (II)* and reveal interesting differences between this and the secondary systems mentioned above. Specifically, in 90% acetone k_{eq}/k_t is 0.60 (*cf.*, 2.2 - 3.2 for the secondary systems) and return proceeds with 96 ± 2% retention (IIa) and 4 ± 2% inversion (IIb), *i.e.*, 8 ± 4% racemization. In 80% acetone k_{eq}/k_t = 0.49 and return results in 10 ± 4% racemization. Thus, return involves much less racemization than in the secondary systems (38 to 53% racemization in 90% acetone).[2,e]



I II

The greater stereospecificity in the tertiary system may result from the greater distance (IIb) separating the anion from the opposite side of the cation; or what amounts to the same thing, a higher barrier for rotation of the cation with

---

* Evidence has been presented[2b] that two intermediates are involved in the *p*-chlorobenzhydryl system; one that returns with complete retention and one that returns with partial racemization. In the present case we have no evidence on this point except that the racemization suggests that two intermediates may be involved.

respect to the anion. A conformational factor may also be involved. In II the ethyl group, and to a smaller extent the methyl group, can be arranged so that one side of the ion is less hindered for bonding than the other. Microscopic reversibility suggests this may be the favored conformation for ionization. In this case if return or capture is faster than conformational equilibration retention would be favored.

From the second-order constant for exchange between I and added C^{14}-labeled *p*-nitrobenzoic acid--10^2 k (*l*. *mole*$^{-1}$ *hr*.$^{-1}$) = 0.72 and 0.34 for 80% and 90% acetone (78.6°), respectively--the amount of exchange between I and accumulating acid can be determined for any stage of the solvolysis.[4] Solvolysis in 90% acetone for 143 hrs. (56% equilibration and ~6% racemization) results in 1% exchange. In 80% acetone exchange is even slower relative to ion-pair return. The intramolecularity of equilibration and racemization and the solvent effects on the rates are consistent with the view that these transformations result from ion-pair return.

Solvolysis of I gives 70% substitution (2-phenyl-2-butanol) and 30% elimination (phenylbutenes) in 80% acetone and 31% substitution and 69% elimination in 90% acetone. The alcohol formed in 80% acetone is 20% as optically pure (retention of configuration) as the average optical purity[8] of the substrate. In 90% acetone solvolysis proceeds with 38% excess retention. Control experiments showed that solvolysis involves >99% alkyl-oxygen cleavage and the alcohol is optically stable under these conditions. The amount of retention is 3-4 times greater than in the *p*-chlorobenzhydryl system (*e.g.*, 10% retention in 90% acetone).[2a] In striking contrast methanolysis of 2-phenyl-2-butyl acid phthalate results in 12% excess inversion.[9] We presume that the unexpectedly high level of retention results from a combination of conformational factors (*vide supra*) and the proximity of the anion in the intermediate.[2a]

Acknowledgement - This work was supported in part by Grant GP-1911 from the National Science Foundation.

REFERENCES

1. National Institutes of Health Predoctoral Fellow.
2. (a) H. L. Goering, R. G. Briody and J. F. Levy, *J. Am. Chem. Soc.*, **85**, 3059 (1963); (b) H. L. Goering and J. F. Levy, *ibid.*, **86**, 120 (1964).
3. Unpublished work by R. G. Briody and J. F. Levy.
4. H. L. Goering and J. F. Levy, *J. Am. Chem. Soc.*, **84**, 3853 (1962).
5. H. L. Goering, J. T. Doi and K. D. McMichael, *ibid.*, **86**, 1951 (1964).
6. Unpublished work by H. Hopf and G. Sandrock.
7. W. Doering and H. H. Zeiss, *J. Am. Chem. Soc.*, **72**, 2391 (1951).
8. Determined as described by S. Winstein and D. Trifan, *J. Am. Chem. Soc.*, **74**, 1154 (1952).
9. H. H. Zeiss, *J. Am. Chem. Soc.*, **75**, 3154 (1953).