nicotinamide,[22] some type of intermediate seems essential. Since *N*-propyldihydronicotinamide reduces I roughly 50,000 times faster than trifluoroacetophenone,[6b] intermediate formation is apparently important for a wide range of reaction rates. A more complete description of the chemical nature of these intermediates should provide a better understanding of the mechanism of catalysis of NAD$^+$ and NADP$^+$-dependent dehydrogenases.

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[22] D. J. Creighton, Ph.D. Thesis, University of California at Los Angeles (1972).

[23] Supported by Public Health Service Training Grant No. GM 00364.

[24] Alfred P. Sloan Research Fellow, 1972–1974.

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Large Polar Effects in the Oxidation of Hexadecanoic (Palmitic) Acid by Nitric Acid

Sir:

Free radicals are noted for their insensitivity to polar effects. For example, photochlorination of 1-chlorobutane with Cl_2 at 68° gave equal rates of attack on C_2 and C_3,[1] and photochlorination of octanoic acid with Cl_2 or *t*-BuOCl in CCl_4 gave comparable amounts of attack on C_4–C_7.[2] This subject has been treated in reviews.[3–5] The major exceptions are reactions involving nitrogen cation (aminium) radicals.[6,7] These exhibit large polar effects. Typical is the 80% selectivity for ω-1 photochlorination in C_6–C_8 acids[7] and esters[6] and the >90% ω-1 selectivity found in C_6–C_8 alcohols.[7,8]

Another type of free radical reaction has now been found which shows large polar effects. This is the nitric acid oxidation of hexadecanoic acid, Table I. At low conversion (6%), 77% of the diacids are C_{10}–C_{15} showing a high selectivity for attack at positions remote from the carboxyl group. As the oxidation progresses, the longer diacids cleave in the middle to produce two molecules of shorter diacids so that the distribution of diacids shifts toward C_4–C_8 (Table I) and obscures the initial high selectivity for remote attack.

Table I. Relative Yields of Dicarboxylic Acids from the Oxidation of 2.56 g of Hexadecanoic Acid with 30 ml of 70% HNO_3 at 90°

Time, hr	4	24	120
Acid product, g	2.60	2.68	2.90
% $C_{15}H_{31}COOH$ reacted	6	80	100

No. of carbons in dicarboxylic acid	Relative yields: 4 hr EGSS-X	4 hr SE-30	24 hr EGSS-X	120 hr EGSS-X
4	0	0	3	8
5	3	0	4	16
6	4	0	7	24
7	4	1	12	26
8	(5)[a]	4	20	16
9	7	8	20	8
10	13	11	14	2
11	13	14	9	0
12	15	17	6	0
13	16	(17)[a]	3	0
14	11	17	2	0
15	9	(11)[b]	0	0
16	0	0	0	0

[a] The value is a mean of the preceding and following value. Direct measurement was prevented because of overlap with unidentified band (total band area 31). Value was estimated from data on EGSS-X column.

The selectivity for remote attack accounts for the facts that little CO_2 or acetic acid is produced and that the net weight of isolated acids increases as the reaction progresses, Table I. It also accounts for the fact that the rate of disappearance of dibasic acids increases with chain length on treatment with 62% HNO_3.[9] The rate constants (in min^{-1}) were $<10^5$ for C_4–C_6 and 2×10^{-4}, 7×10^{-4}, 3×10^{-3}, and 2×10^{-2} for C_7–C_{10}. The data in Table I also show that the longer chain diacids are selectively oxidized.

The increase in weight in going from reactant to products makes this an attractive method for the production of C_5–C_8 diacids. On the basis that the distribution at 6% conversion indicates the initial cleavage and given the distribution at 120 hr, the theoretical yield of diacids is 3.0 g. This is in good agreement with the 2.9 g isolated and further shows the absence of oxidations other than the remote oxidation pattern described.

For the early stages (6% conversion), there was concern that keto acids were present in the products (hydroxy acids were unlikely because hydroxy compounds instantly produce copious NO_2 on contact with 70% HNO_3). The general agreement between gc analyses on the polar EGSS-X and the nonpolar SE-30 columns (Table I) indicated that keto esters were not a major problem. In agreement, an infrared spectrum showed a keto band at 1410 cm^{-1} that was only about 5% of the area of the ester carbonyl band at 1440 cm^{-1}. However, a band which is suspected of being due to a keto ester appeared between C_9 and C_{10} on the EGSS-X column and coincided with the C_{15} band on the SE-30 column. A similar pattern was found in model studies on the oxidation of 12-hydroxystearic acid with 70% HNO_3 at 90°.

The preliminary results are reported now because of (1) the industrial importance of oxidizing fatty acids to long chain diacids and (2) the unusually large polar effects found for this free radical reaction.

There is no direct evidence identifying the attacking radical in the HNO_3 oxidation, although the abundance

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of NO_2 gives it first consideration. If it is NO_2 and if it is the N in NO_2 that bonds to the abstracted H, then there is a resemblance between chlorinations *via* $R_2NH\cdot^+$ and oxidations *via* NO_2. In both cases, a highly electron withdrawing group is attached to a nitrogen radical.

The reactions were stirred with a mechanical stirrer. Excess NO_2 was vented through a water trap. Two phases were present initially at 90°, but the mixture became homogeneous as the reaction progressed.

The monoacids and diacids were isolated by cooling to 25°, diluting to 10% HNO_3, saturating with Na_2SO_4, extracting with ether, and removing the ether. After weighing, the acids were analyzed by conversion to their methyl esters with CH_2N_2 and gas chromatography of the esters. Both EGSS-X and SE-30 0.25-in. columns[10] were used because the retention time of methyl hexadecanoate was close to that of dimethyl octanedioate on the EGSS-X column and close to that of dimethyl tridecanedioate on the SE-30 column. Retention times and response curves were determined using authentic samples of the methyl esters of the C_3, C_5–C_8, C_{10}, C_{12}, C_{14}, and C_{16} monoacids and C_6–C_{10}, C_{12}, C_{14}, and C_{16} diacids.

Preliminary studies on the C_8, C_{10}, C_{12}, and C_{14} monoacids confirm the principles established with hexadecanoic acid. There have been numerous studies of HNO_3 oxidations of alcohols and ketones to diacids and a few studies on HNO_3 oxidation of crude hydrocarbon fractions to small diacids. The two subjects have been reviewed,[11] but neither are directly germane to this report.

Acknowledgment. This work was supported by a grant from the National Science Foundation. This support is gratefully acknowledged.

[10] Columns supplied by Applied Science Laboratories, State College, Pa., 16801.

[11] E. H. Pryde and J. C. Cowan in "Condensation Monomers," J. K. Stille, Ed., Wiley, New York, N. Y., Chapter 1.

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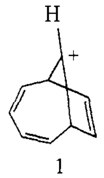
Rearrangement Reactions of Bicyclo[4.2.1]nona-2,4,7-trien-9-yl Cations[1]

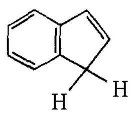
Sir:

The bicyclo[4.2.1]nona-2,4,7-trien-9-yl cation (**1**) and its derivatives are of interest with respect to their properties,[1,2] the processes by which they isomerize,[1,2a–d] and their possible homoaromaticity[2e] and bicycloaromaticity.[2e–g] We should now like to describe further the behavior of bicyclo[4.2.1]nona-2,4,7-trien-9-yl cations and clarify their paths of rearrangement.[2d]



1

syn-Bicyclo[4.2.1]nona-2,4,7-trien-9-yl *p*-toluenesulfonate[3] (**2**) and di-*syn*-bicyclo[4.2.1]nona-2,4,7-trien-9-yl sulfite have each been reported to give indene (**3**) when heated;[2d] decomposition of **2** in the presence of lithium aluminum hydride yields *cis*-8,9-dihydroindene (**4**).[2d] The **3** and **4** apparently arise from the *cis*-8,9-dihydro-1-indenyl cation (**5**) generated.[4] Of the overall routes by which **1** (=**1a**) might isomerize to **5** (=**9** and **10a** or **14a**), two of the most prominent possibilities involve bishomotropylium ion processes resulting from (1) interaction of the diene bridge (eq 1) with the cationic center (C-9) and the monoene bridge and migration of C-2 or C-5 to C-9 to yield cation **8a** *via* **7a**[2d,5] and (2) bridging of C-7 and C-8 of the monoene unit (eq 1) with the cationic site (C-9) and with C-2 and C-5 of the diene system to give **13a**[5] *via* reorganization of **12a**. Mechanisms analogous to that of eq 1 are apparently involved in conversion of *syn*-9-hydroxy-9-phenylbicyclo[4.2.1]nona-2,4,7-triene (**15**) by thionyl chloride and pyridine, *via* **1a**, to *exo*-1-chloro-9-phenyl-*cis*-8,9-dihydroindene[2b,6] and in isomerization of bicyclo[4.2.1]nona-2,4,7-trien-9-one (**16**) to 1-indanone by boron trifluoride[2d] in ethyl ether or *p*-toluenesulfonic acid[1] in benzene.



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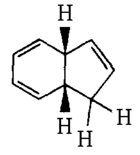

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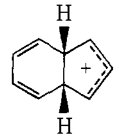

5

It is now reported that 9-deuterio-*syn*-bicyclo[4.2.1]-nona-2,4,7-trien-9-yl *p*-toluenesulfonate (mp 83–85°, lit[2d] mp 83–85°), prepared by reduction of **16** with sodium borodeuteride in deuterium oxide–methanol-*O-d* and reaction of the 9-deuterio-*syn*-9-hydroxybicyclo-[4.2.1]nona-2,4,7-triene (mp 51–52.5°, lit.[2d] mp 51–52.5°) with *p*-toluenesulfonyl chloride in pyridine, is converted at 74° in dimethyl sulfoxide to 2-deuterioindene (**14c**, eq 2, >74% yield). The indene isolated contains one atom of deuterium per molecule and its nmr spectrum, τ 2.71 (m, 4 H, aromatic H), 3.18 (m, 1 H, H at C-1), and 6.66 (m, 2 H, H at C-3), is identical with that of **14c** obtained by reducing 2-indanone (**18**) with sodium borodeuteride in deuterium oxide–methanol-*O-d*, reaction of 2-deuterio-2-indanol with *p*-toluenesulfonyl chloride–pyridine, and elimination of 2-deuterio-2-indanyl *p*-toluenesulfonate with potassium *tert*-butoxide in dimethyl sulfoxide. Conversion of **17** to **14c** thus occurs by a sequence as in eq 2 and

[1] This research is abstracted primarily from the Ph.D. Dissertation of D. C. Sanders, The Ohio State University, Columbus, Ohio, 1972; *Diss. Abstr. B*, **33**, 3561 (1973).

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[3] In naming bicyclo[4.2.1]nona-2,4,7-trienes, the substituent at C-9 cis to the diene bridge is designated as syn.

[4] Cation **5** may give **3** by elimination and sigmatropic rearrangement or/and by rearrangement and elimination.

[5] It is to be emphasized that when Z = H (eq 1 and 2), **7a** and **12a** are identical chemically when equivalently delocalized.

[6] Reference 2b has also found that *exo*-1-hydroxy-9-phenyl-*cis*-8,9-dihydroindene is converted by *p*-toluenesulfonic acid, possibly *via* **8b** (eq 1), to 1- and 3-phenylindenes (**9b** and **10b**).