[CONTRIBUTION FROM ROHM AND HAAS CO., REDSTONE ARSENAL RESEARCH DIVISION]

aci-Nitroalkanes. II. The Mechanism of the Nef Reaction[1]

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The kinetics of the acid-catalyzed solvolysis of seven *sec-aci*-nitroalkanes has been determined in a nitrogen atmosphere at 0° in 80% by volume methanol by the use of a newly developed spectrophotometric microanalytical method for *aci*-nitroalkanes. All kinetics were conducted with approximately 1×10^{-3} M *aci*-nitroalkane solutions. In each case the reaction was found to be first order in both *aci*-nitroalkane and hydrogen ion and reproducible to ±15%. Spectrophotometric product analyses for nitroalkanes indicated that, with the possible exception of nitrocyclobutane, no detectable amounts of nitroalkane were regenerated under kinetic conditions. Product isolation experiments indicated that each of the *aci*-nitroalkanes studied gave excellent yields of the corresponding ketones (isolated as 2,4-dinitrophenylhydrazones) on hydrolysis under conditions similar to those of the kinetic experiments and very little if any pseudonitrole. The *sec-aci*-nitroalkane reactivity sequence cyclohexyl > cyclobutyl > 2-propyl > 1-cyclopropylethyl > cyclopentyl > dicyclopropylmethyl > cycloheptyl was observed and when coupled with the first-order dependence of reaction rate on both hydrogen ion and *aci*-nitroalkane concentrations, leads to the conclusion that the rate-determining step of the Nef reaction is most probably the nucleophilic attack of solvent on the unsaturated carbon atom of the conjugate acid of the *sec-aci*-nitroalkane. The near average reactivity of the cyclopropyl-substituted nitroalkanes is discussed. The ultraviolet absorption spectra of the anions of these latter nitroalkanes show a marked shift of their absorption maxima to longer wave lengths when compared with the absorption spectra of anions of other representative *sec*-nitroalkanes.

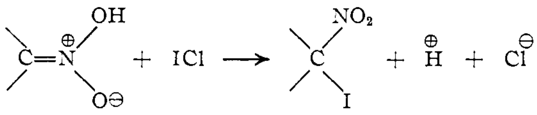
Although the hydrolysis of *aci*-nitroalkanes (Nef reaction) often has been utilized as a synthetic method for the preparation of carbonyl compounds[2] and a mechanism recently has been proposed,[3] no kinetic studies of this reaction have been reported. Because of this lack of quantitative information, the present investigation was initiated in an effort to bring the mechanism of this reaction more sharply into focus and to secure additional information with regard to the stereoelectronic requirements of *aci*-nitroalkanes.

Secondary nitroparaffins were chosen for study since diverse members of this series are easily prepared by the trifluoroperoxyacetic acid oxidation of the corresponding oximes[4] and the hydrolysis of their *aci*-isomerides has been shown[2,3] to produce the corresponding ketones in high yield. Nitrocycloalkanes received particular attention since their kinetic examination coupled with the recent generalizations of Brown, Brewster and Shechter[5] provided a tool which was used to specify the probable course of the reaction.

Kinetic Method

In order to examine the rates of the acid-catalyzed hydrolysis of *sec-aci*-nitroalkanes, certain experimental requirements were necessarily imposed on any method chosen. These include: (1) the use of low *aci*-nitroalkane concentrations which would minimize the importance of bimolecular side reactions which might occur between *aci*-nitroalkane molecules, (2) the generation of the anions of the nitroalkanes in an atmosphere containing no oxygen,[6] (3) a method for the instantaneous addition of strong acid to the nitroalkane anion solution with a minimum temperature increase and the ultimate production of a predetermined hydrogen ion concentration, (4) an analytical method for the determination of *aci*-nitroalkane at low concentrations and in the presence of a moderate concentration of strong acid.

These requirements were met and the rates of acid-catalyzed hydrolysis of seven *sec-aci*-nitroalkanes were determined at 0° in 80% by volume methanol using a spectrophotometric adaptation of the classical halometric determination of *aci*-nitroalkanes[7] described by equation (1).



(1)

Each rate run was carried out under nitrogen. Approximately 1×10^{-3} M concentrations of *aci*-nitroalkanes were generated in a stirred reactor in the presence of known hydrogen ion concentrations by the addition of a known and excess amount of concentrated hydrochloric or perchloric acid to a solution of nitroalkane anion.[8]

The nitroalkane anion was prepared under nitrogen in the reactor from a known volume of standardized dilute sodium hydroxide solution in 80% methanol and approximately 3 mg. of nitroalkane.

In essence, the analytical method consisted of the rapid addition of an aliquot of reaction mixture to a known and excess amount of iodine monochloride in aqueous methanol solution followed by the addition of a small portion of an intimate mixture of N,N,N′,N′-tetramethyl-*p*-phenylenediamine dihydrochloride and sodium acetate. The excess iodine monochloride rapidly and quantitatively reacted as

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[1] This research was carried out under Army Ordnance Contract W-01-021-ORD-334.

[2] See W. E. Noland, *Chem. Revs.*, **55**, 137 (1955), for a critical review and many examples of the synthetic applications of this reaction.

[3] E. E. van Tamelen and R. J. Thiede, THIS JOURNAL, **74**, 2615 (1952).

[4] W. D. Emmons and A. S. Pagano, *ibid.*, **77**, 4557 (1955).

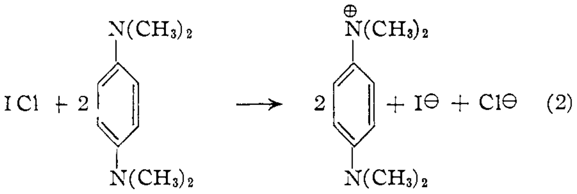
[5] H. C. Brown, J. H. Brewster and H. Shechter, *ibid.*, **76**, 467 (1954), have successfully correlated the relative thermodynamic stabilities of cycloalkyl systems having *exo*-cyclic double bonds in terms of alkyl hydrogen eclipsing and I-strain; see also H. C. Brown and G. Ham, *ibid.*, **78**, 2735 (1956).

[6] G. A. Russell, *ibid.*, **76**, 1595 (1954), reported the facile oxygenation of the 2-nitropropane anion to produce acetone and nitrite ion.

[7] K. H. Meyer and P. Wertheimer, *Ber.*, **47**, 2347 (1914).

[8] The temperature increase of reaction solution was minimized by the use of small quantities of base and acid and by operating in dilute solution. The hydrogen ion concentration was calculated on the assumption that all the *aci*-nitroalkanes employed were weak acids (*p*Ka 4–6) and that they were present in an undissociated state. In one run perchloric acid was substituted for hydrochloric acid without changing the result.

in (2) to produce an intensely blue solution of the Würster ion.[9]



(2)

ϵ = 13,000 at 622 mμ

The spectrophotometric determination of the amount of Würster ion produced allowed the calculation of the instantaneous concentration of *aci*-nitroalkane present in the aliquot taken. Since the stoichiometry of (1) is cleanly observed, each *aci*-nitroalkane examined was in this manner given an effective extinction coefficient of 2.6×10^4 at 622 mμ.

Results

Each *sec*-*aci*-nitroalkane examined in the manner described above gave acceptable first-order plots with the determined first-order rate constant reproducible to ±15% and proportional to the hydrogen ion concentration. The instantaneous rate expression is then defined by (3).

$$v = k[\mathrm{H}^+]\,[\textit{aci}\text{-nitroalkane}] \qquad (3)$$

Figure 1 is a typical first-order plot obtained with *aci*-nitrocyclohexane and Fig. 2 illustrates the fit of all the data obtained to equation 3. It should be noted that within experimental error all of the lines in Fig. 2 pass through the origin. This observation rules out the occurrence of a kinetic term of the form 4 which would result if *aci*-nitro-

$$v = k'[\textit{aci}\text{-nitroalkane}] \qquad (4)$$

alkane were tautomerizing to the nitroalkane at a significant rate.[10]

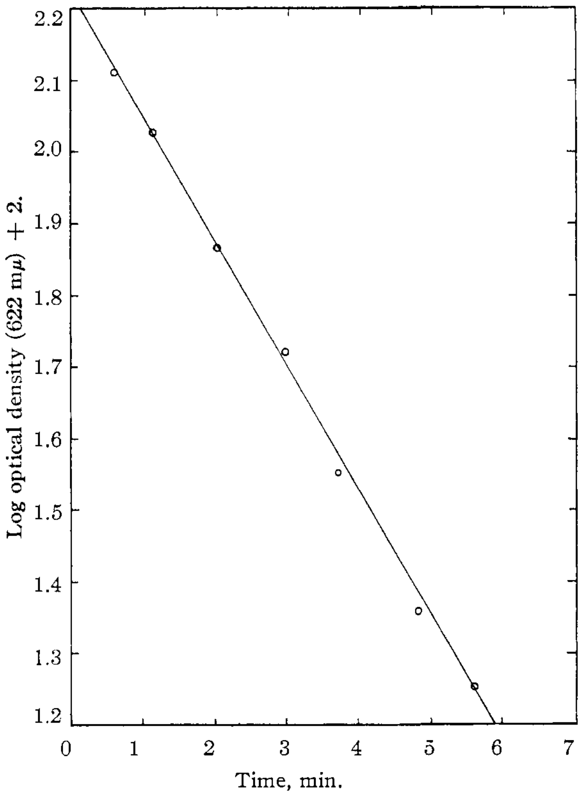


Fig. 1.—First-order plot of the solvolysis of *aci*-nitrocyclohexane in 80% methanol at 0.0° containing 4.4×10^{-2} *M* hydrochloric acid.

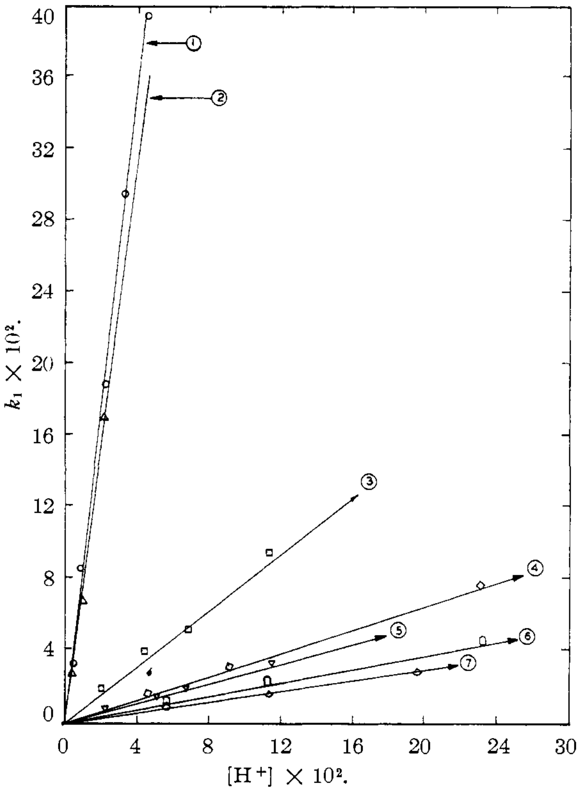


Fig. 2.—Dependence of pseudo first-order rate constant on hydrogen ion concentration for: nitrocyclohexane, 1; nitrocyclobutane, 2; 2-nitropropane, 3; nitrocyclopentane, 4; 1-cyclopropylnitroethane, 5; dicyclopropylnitromethane, 6; and nitrocycloheptane, 7.

Table I summarizes the second-order rate constants obtained in the hydrolysis of *aci*-nitrocyclobutane, -cyclopentane, -cyclohexane, -cycloheptane, 2-*aci*-nitropropane, *aci*-nitrocyclopropylethane and *aci*-nitrodicyclopropylmethane. With the exception of nitrocyclohexane and 2-nitropropane, all the parent nitroalkanes were prepared by the peroxytrifluoroacetic acid oxidation of the corresponding oximes.[4] The two cyclopropyl compounds reported here were each obtained in approximately 40% yield.

Product analyses were carried out in every case for both regenerated nitroalkane and for the ketone product of the Nef reaction. The analytical procedure applied to the former possible product was based on the treatment of the reaction mixture with strong base in a nitrogen atmosphere followed

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[9] L. Michaelis, M. P. Schubert and S. Granick, THIS JOURNAL, **61**, 1981 (1939).

[10] R. G. Pearson and R. L. Dillon, *ibid.*, **72**, 3574 (1950), have shown that in the case of nitroethane this tautomerization reaction is observed kinetically as the reaction of nitroalkane anion with general acids, $RNO_2^- + HA \rightarrow RHNO_2 + A^-$. The kinetic isolation of the acid-catalyzed hydrolysis of *aci*-nitroalkane at relatively high acid concentrations is to be expected on the basis of the difference in transition state composition of the two competing processes.

TABLE I

COLLECTED SECOND-ORDER RATE CONSTANTS FOR THE NEF REACTION IN 80% METHANOL AT 0.0°

Nitroalkane	Second-order rate constant, l./mole-min.	Range of [H⁺] examined, mole/l.
2-Nitropropane	0.78 ± 0.08	2×10^{-2} to 1×10^{-1}
Nitrocycloheptane	0.14 ± .02	5×10^{-2} to 2×10^{-1}
Nitrocyclohexane	8.9 ± .50	3×10^{-3} to 4×10^{-2}
Nitrocyclopentane	0.32 ± .05	4×10^{-2} to 2×10^{-1}
Nitrocyclobutane[a]	8.0 ± .50	3×10^{-3} to 2×10^{-2}
Dicyclopropylnitromethane	0.18 ± .02	1×10^{-1} to 3×10^{-1}
1-Cyclopropylnitroethane	0.27 ± .03	1×10^{-1} to 5×10^{-1}

[a] The rate constant reported for this nitroalkane is questionable due to the fact that some product other than cyclobutanone was found in the reaction product.

by the spectrophotometric examination of the resulting solution in the 220 to 250 mμ region. Since the anions of all the nitroalkanes used absorb strongly in this region, the presence of nitroalkane should be detected easily among the reaction products. With the single exception of nitrocyclobutane, no regenerated nitroalkane was found in any case examined. Nitrocyclobutane, after acid-catalyzed hydrolysis and treatment with alkali, gave an absorption peak at 230–234 mμ. The optical density of this peak would account for one-sixth of the nitrocyclobutane utilized in the run if the extinction coefficient of the product were the same as that of the nitrocyclobutane anion. It appears that nitrocyclobutane does not give the Nef reaction quantitatively under the conditions employed. That the material responsible for the 230–234 mμ peak in the products was not due to nitrocyclobutane, which escaped the initial treatment with hydroxide ion, was shown by the fact that this absorption was independent of the time allowed for the initial ionization reaction.

Table II summarizes the absorption maxima of the nitroalkane anions employed in this study. The striking bathochromic shift observed on the introduction of α-cyclopropyl rings into a *sec*-nitroalkane lends considerable support to the concept of the unsaturated character of cyclopropyl groups.[11]

TABLE II

THE ULTRAVIOLET ABSORPTION SPECTRA OF NITROALKANE ANIONS IN 80% METHANOL

Parent nitroalkane	λ_{max}, mμ	$\epsilon_{max} \times 10^{-4}$[a]
2-Nitropropane	227	1.06
Nitrocycloheptane	234	1.15
Nitrocyclohexane	237	1.20
Nitrocyclopentane	230	1.13
Nitrocyclobutane	234	1.17
Dicyclopropylnitromethane	248	1.17
1-Cyclopropylnitroethane	240	1.25

[a] Values dependable to only ±5%.

The second product analysis employed involved the execution of the rate experiments at somewhat higher (*ca.* 0.07 *M*) *aci*-nitroalkane concentrations and the isolation of the resulting ketone as its 2,4-dinitrophenylhydrazone. In these runs, a fleeting blue intermediate always was observed. Pseudonitrole formation was noted only in the cases of cyclopropylnitroethane and dicyclopropylnitromethane. However, the pseudonitrole produced amounted to only 1–2% of the nitroalkane used, and it is concluded that this reaction did not play an important role in the kinetic studies.[12]

Table III presents the yield data for the series of nitroalkanes examined and gives considerable support to the assumed course of the reaction. The somewhat lower yield of 2,4-dinitrophenylhydrazone obtained from nitrocyclobutane may be due to the incomplete separation of the ketone as the solid derivative. However, as stated above, spectrophotometric examination of an alkaline solution of the reaction products of nitrocyclobutane did show absorption in the 230 mμ region, and it is conceivable that the Nef reaction may here take another course and produce correspondingly less cyclobutanone.

TABLE III

COLLECTED PRODUCT ANALYSIS DATA FOR THE NEF REACTION IN 80% METHANOL AT 0.0°

Parent nitroalkane	Crude ketone 2,4-dinitrophenylhydrazone Yield, %	Crude ketone 2,4-dinitrophenylhydrazone M.p., °C.	M.p. pure 2,4-dinitrophenylhydrazone, °C.
2-Nitropropane	76	124–126	126[a]
Nitrocycloheptane	94	145–146	148[a]
Nitrocyclohexane	97	158–159	162[a]
Nitrocyclopentane	89	136–138	142[a]
Nitrocyclobutane	56	142	146[b]
Dicyclopropylnitromethane	96	189–191	193[c]
1-Cyclopropylnitroethane	64	140–142	155[d]

[a] Melting points taken from R. L. Shriner and R. C. Fuson, "The Systematic Identification of Organic Compounds," 2nd Ed., John Wiley and Sons, Inc., New York, N. Y. [b] N. J. Demjanov and M. Dojarenko, *Ber.*, **55**, 2739 (1932). [c] Melting point of pure authentic samples prepared in the usual fashion and recrystallized to constant m.p. *Anal.* Calcd. for $C_{13}H_{14}N_4O_4$: C, 53.78; H, 4.86. Found: C, 53.50; H, 4.78. Ketone obtained from the Aldrich Chemical Co., Milwaukee, Wis. [d] J. D. Roberts and C. Green, THIS JOURNAL, **68**, 214(1946), give m.p. of 149–150°.

Discussion

Any mechanism which is proposed for the Nef reaction must take into account a number of facts: (1) the rate-determining transition state for the decomposition of *aci*-nitroalkane is composed of an *aci*-nitroalkane molecule, a proton and probably one or more molecules of hydroxylic solvent. (2)

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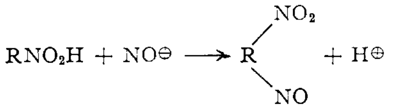
[11] R. H. Eastman and S. K. Freeman, THIS JOURNAL, **77**, 6642 (1955), and previous papers of this series.

[12] Pseudonitrole formation is at present best accounted for in terms of spurious quantities of nitrite ion in the reaction mixture. The ultimate source of nitrite ion may be an impurity in the parent nitroalkane or the result of air oxidation of the nitroalkane anion. Regardless of the source, the reaction producing pseudonitrole probably occurs between nitrosonium ion or its precursor, H_2^+ONO and *aci*-nitroalkane or nitroalkane anion.

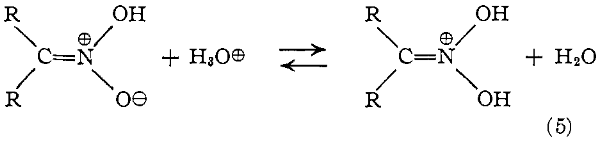


$$RNO_2H + NO^{\ominus} \longrightarrow R\begin{matrix} NO_2 \\ NO \end{matrix} + H^{\oplus}$$

Such a process would make a much smaller contribution to the over-all course of *aci*-nitroalkane decomposition in the low concentration kinetic experiments than the preparative experiments due to its second-order character.

The reactivity sequence, *aci*-nitrocyclohexane > -nitrocyclobutane > -nitropropane > -nitrocyclopentane > -1-cyclopropylnitroethane > -dicyclopropylnitromethane > -nitrocycloheptane is observed. (3) A blue intermediate having an appreciable lifetime is produced. (4) *aci*-Nitroalkanes having enhanced resonance stabilization do not normally give the Nef reaction[3] or do so only very slowly.

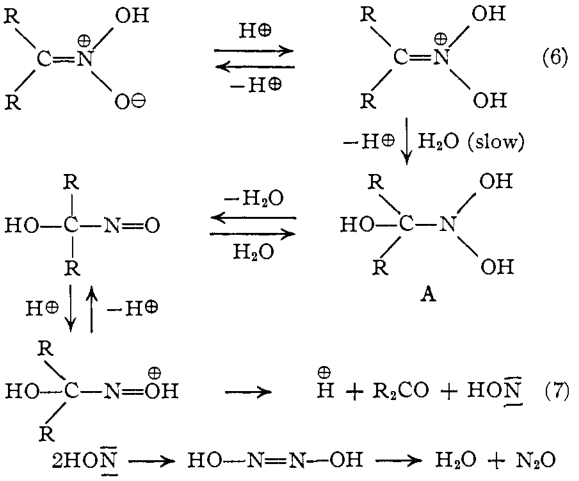
The bare fact that the first slow step of the Nef reaction involves a protonated *aci*-nitroalkane molecule immediately suggests the possibility that equilibrium (5) plays an important role in the reaction.



(5)

Thus, the conjugate acid of the *aci*-nitroalkane molecule which is produced in this equilibrium would have an electron-deficient carbon atom attached to nitrogen and would be labile to nucleophilic attack at this carbon atom. This tentative conclusion is further strengthened by the consideration of the relative rates of reaction found in the nitrocycloalkane series as follows: Brown, Brewster and Shechter[5] have recently summarized a great deal of reactivity data which leads to the postulate that a 5-ring having an exocyclic double bond is always extremely stable relative to its 6-ring counterpart. This observation is rationalized by these authors in terms of bond opposition interactions. On somewhat different grounds one would expect a 4-ring having an exocyclic double bond to be quite reactive due to internal bond angle deformation and the 7-ring system should appear much as the cyclopentyl derivative. The fact that at 0° *aci*-nitrocyclohexane is hydrolyzed 27 times faster than *aci*-nitrocyclopentane and 11 times faster than *aci*-nitropropane, and *aci*-nitrocyclobutane is nearly as reactive as the cyclohexyl compound (this latter result should be accepted with caution, *vide supra*) leads to the conclusion that the carbon–nitrogen double bond of the reactive conjugate acid of an *aci*-nitroalkane is destroyed in the first slow step.

The question of the role of the blue intermediate which is observed during a preparative Nef reaction cannot be answered definitely at this time. However, the very fact that it persists at a detectable concentration level while *aci*-nitroalkane is being destroyed[13] indicates that it is a relatively stable species. Since the intense blue color of these intermediates strongly suggests the presence of a nitroso group, they may be tentatively formulated[2] as α-hydroxynitrosoalkanes which may arise as in (6) and decompose to ketone and nitrous oxide by one of many possible paths such as (7).[14]

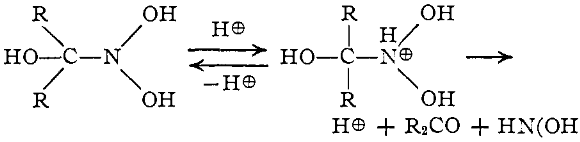


(6)

(7)

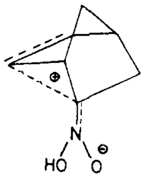
$$2HO\bar{N} \longrightarrow HO{-}N{=}N{-}OH \longrightarrow H_2O + N_2O$$

A similar mechanism has been proposed by van Tamelen and Thiede,[8] but these authors prefer to write the decomposition of the intermediate A by acid-catalyzed cleavage followed by the conversion of $HN(OH)_2$ to nitrous oxide and water.



Since the α-hydroxynitrosoalkane intermediate postulated above may be in mobile hydrolytic equilibrium with A, these paths are presently indistinguishable.[15]

The reluctance of highly resonance stabilized *aci*-nitroalkanes to undergo the Nef reaction has been discussed previously in terms of stabilization of the reactant. Notable examples of this class of nitroalkanes are α-phenylnitroethane[16] and phenylnitromethane which give hydrolytically stable *aci*-nitro tautomers on acidification of their anions with strong mineral acids.[17] Similarly, Wildman and Saunders[18] report that the 5-nitrobicyclo-[2,2,1]2-heptenes fail to undergo the Nef reaction and these authors attribute this inertness to the stabilization of the *aci*-nitrotautomer by the 1,3-interaction shown in B.



B

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[13] In the preparative experiments carried out in this study the acid concentration was such as to give the calculated half life of the *aci*-nitroalkane a duration of only a few minutes in the slowest cases. The blue intermediate often was found to persist in these same experiments for as long as two to four minutes.

[14] D. C. Iffland and G. X. Criner, *Chemistry & Industry*, 176 (1956), has described compounds obtained by the reaction of lead tetraacetate with ketoximes and believed to be α-acetoxynitrosoalkanes. Acid hydrolysis of these materials yields the corresponding ketone presumably *via* an α-hydroxynitroso intermediate. M. F. Hawthorne and R. D. Strahm have found that the second-order silver ion catalyzed solvolysis of 1-chloro-1-nitrosocyclohexane in aqueous acetonitrile produces cyclohexanone in 90% yield, nitrous oxide and no hydroxylamine. This reaction sequence most likely passes through 1-hydroxy-1-nitrosocyclohexane and will be described in detail in the following paper of this series.

[15] Additional processes may be proposed such as the acid-catalyzed dimerization of the α-hydroxynitrosoalkane followed by the elimination of HON=NOH and two molecules of ketone.

[16] E. Bamberger and R. Seligman, *Ber.*, **36**, 706 (1903).

[17] N. Kornblum and G. E. Graham, THIS JOURNAL, **73**, 4041 (1951).

[18] W. C. Wildman and D. R. Saunders, *J. Org. Chem.*, **19**, 381 (1954).

In view of these observations it was of interest to examine both kinetically and product-wise other stabilized systems which might be more reactive than those examples cited above, but yet show some retardation due to electronic stabilization of the reactant *aci*-nitroalkane. Such a study would necessarily indicate the relative electronic demands of the reactant *aci*-nitroalkane and the kinetically observed transition state. Since much recent evidence[10] has shown that the cyclopropyl ring will stabilize high energy species by its ability to interact with neighboring *p*-orbitals, it was believed that the *aci*-nitro tautomers of cyclopropylnitroethane and dicyclopropylnitromethane might be sufficiently stabilized relative to their respective hydrolytic transition states so as to produce rate retardations and perhaps abnormal products. The results given in Table I and III show that this is not the case since the rates of hydrolysis of these two *aci*-nitroalkanes are no less than would be expected on the basis of steric hindrance to the attack of solvent and the corresponding ketones are obtained in high yield. It therefore appears as though the electronic demands of the *aci*-nitroalkane reactant and the transition state are roughly the same in these two cases. This result implies that the positive charge gained by the *aci*-nitroalkane in going to its conjugate acid has been lost to the attacking solvent in the succeeding transition state. In the cases of α-phenylnitroethane and phenylnitromethane the increased stability of the *aci*-nitrotautomers may shift the rate-determining transition state so far toward products that the positive charge of the reactant *aci*-nitrotautomers is almost wholly held by nucleophilic solvent in the transition state.[19] The unsaturation afforded the system by the phenyl group would thus stabilize the reactant species but would not appreciably stabilize the rate-determining transition state and a rate retardation would result.

Experimental[20]

2-Nitropropane was obtained from Mathieson, Coleman and Bell, Inc., and distilled through a 50–75 plate center-rod distillation column at atmospheric pressure. After a small forerun, the center portion of the material was taken; b.p. 119.5°, $n^{20}\text{D}$ 1.3940.

Nitrocyclohexane from Mathieson, Coleman and Bell, Inc., was fractionated using a Helipak packed column of *ca.* 20 plates efficiency at 15 mm. A center portion boiling at 102° and $n^{20}\text{D}$ 1.4619 was taken for use.

Nitrocyclobutane was obtained in 32% yield from 5.0 g. of cyclobutanone oxime using the trifluoroperoxyacetic acid method of Emmons and Pagano[4] with a disodium acid phosphate acid scavenger. The crude product was twice distilled through a Holzman column[21] at 40 mm.; b.p. 78–79°, $n^{20}\text{D}$ 1.4429.[22]

Nitrocyclopentane,[23] b.p. 90° (40 mm.) and $n^{20}\text{D}$ 1.4518, was prepared as previously described.[4]

Nitrocycloheptane,[23,24] b.p. 101° (15 mm.) and $n^{20}\text{D}$ 1.4721, was prepared as previously described.[4]

1-Cyclopropylnitroethane.—To 7.4 g. (0.075 mole) of crude cyclopropylmethyl ketoxime was added 200 ml. of pure acetonitrile, 2.0 g. of dry urea and 78 g. of disodium acid phosphate. The mixture was brought to reflux with stirring, and a trifluoroperoxyacetic acid solution prepared from 5.5 ml. (0.20 mole) of 90% hydrogen peroxide and 34.0 ml. (0.24 mole) of trifluoroacetic anhydride in 50 ml. of acetonitrile was added slowly over a 1-hr. period. Stirring and refluxing was continued for one additional hour. The mixture was cooled, poured into one liter of water and extracted with ether three times. The combined ether extracts were washed three times with water, dried over magnesium sulfate and concentrated to an oil under a small column. The residual oil was fractionated with a Holzman column giving 3.5 g. (42%) of 1-cyclopropylnitroethane, b.p. 70° at 22 mm., $n^{15}\text{D}$ 1.4338.

Anal. Calcd. for $C_5H_9NO_2$: C, 52.16; H, 7.88. Found: C, 52.30; H, 7.98.

Dicyclopropylnitromethane was prepared in the same manner as 1-cyclopropylnitroethane from 12.5 g. (0.10 mole) of crude dicyclopropylketoxime melting at 67°.[25] Distillation of the crude product through a Holzman column[21] afforded 4.9 g. (35%) of dicyclopropylnitromethane, b.p. 110° (15 mm.), $n^{15}\text{D}$ 1.4619.

Anal. Calcd. for $C_7H_{11}NO_2$: C, 59.55; H, 7.85. Found: C, 59.87; H, 8.00.

Kinetic Procedure.—All kinetic measurements were made at 0° by the use of a 4-liter Dewar flask cryostat containing a well-stirred mixture of ice and water. The reaction vessel was a 150-ml. wide-neck test-tube shaped flask having a Tru-bore stirrer powered by a variable-speed direct current motor. A nitrogen inlet and outlet were attached to the apparatus as was a tightly-stoppered sampling port. "Prepurified" grade nitrogen was supplied directly from the tank through a pressure regulator. Stopcocks on the gas line were arranged in such a manner as to allow rapid sweeping of the system or maintenance of a few millimeters of positive pressure in the closed system. This nitrogen pressure was maintained during each run and prevented the admittance of air when aliquots of reaction mixture were removed through the open sampling port.

The procedure is as follows: The system was thoroughly flushed with nitrogen, and 200 ml. of 0.060 *N* sodium hydroxide in 80% methanol was introduced under nitrogen through the open sampling port. Exactly 0.003 ml. (essentially 3 mg. of each compound investigated) of nitroalkane was added to the sodium hydroxide solution in the same manner. The port was then closed with a rubber stopper and the solution briefly stirred with the attached stirrer. This reaction mixture was allowed to stand under nitrogen for 1 hr. to ensure complete conversion of the nitroalkane to its sodium salt. The reaction vessel was then immersed in the ice–water cryostat, 50 ml. of 80% methanol added and the solution brought to 0° during a 20-minute period. To initiate the Nef reaction, a small accurately measured volume (0.025 to 1.00 ml.) of 12.00 *N* hydrochloric acid was rapidly introduced beneath the surface of the reaction mixture while the solution was vigorously stirred. The use of extremely dilute solutions minimized the effect of heat of neutralization on the temperature of the reaction system. At intervals, 2.00-ml. aliquots of reaction solutions were removed through the sampling port by the use of an automatic pipet. The pipet previously had been cooled to 0° by immersion in a methanol-bath which in turn was cooled by ice and water. The contents of the pipet were discharged into a 10-ml. volumetric flask containing 3 ml. of *ca.* 4×10^{-4} *M* iodine monochloride in 80% methanol. The color of the iodine monochloride faded instantaneously, and the time of delivery was taken as the time of the point. About 20 mg. of an intimately ground mixture of equal weights of sodium acetate and N,N,N',N'-tetramethyl-*p*-phenylenediamine was added to the flask, the flask shaken to effect conversion to Würster's blue, the solution made up to volume with 80% methanol and the optical density determined at 622 mμ with a Beckman model DK-1 recording spectrophotometer. Preliminary experiments with accurately titrated iodine monochloride solutions gave a value of 1.3×10^4 for the extinction coefficient of Würster's blue at that wave length. Optical density values were within 5% of the theoretical

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[19] G. S. Hammond, THIS JOURNAL, **77**, 334 (1955).

[20] All melting and boiling points are uncorrected.

[21] C. W. Gould, G. Holzman and C. Niemann, *Anal. Chem.*, **20**, 361 (1948).

[22] D. C. Iffland, G. X. Criner, M. Koral, F. J. Lotspeich, Z. B. Papanastassiou and S. M. White, Jr., THIS JOURNAL, **75**, 4044 (1953), report b.p. of 77° (40 mm.) and $n^{20}\text{D}$ 1.4432.

[23] D. C. Iffland, *et al.* (ref. 21), report $n^{25}\text{D}$ 1.4518 for nitrocyclopentane and $n^{20}\text{D}$ 1.4710 for nitrocycloheptane.

[24] W. D. Emmons and A. S. Pagano report $n^{20}\text{D}$ 1.4720 for nitrocycloheptane (ref. 4).

[25] H. Hart and O. E. Curtis, THIS JOURNAL, **78**, 112 (1956), report m.p. 76–77°.

values calculated on the basis of complete conversion of nitroalkane to anion and complete reaction of the resulting *aci*-nitro tautomer. Acid concentrations present in each run were calculated on the basis of negligible ionization of the *aci*-nitroalkane and by the relationship

$$[H^+] = \frac{N(\text{ml. } N \text{ normal acid used}) - 2.00\,(N \text{ of base used})}{52.0}$$

In each run an acceptable first-order constant was obtained from log (optical density) *vs.* time plots. Figures 1 and 2 present the data obtained from one nitrocyclohexane run and from all runs with all nitroalkanes, respectively. Table I summarizes all second-order rate constants.

Spectrophotometric Measurements.—The ultraviolet absorption spectra of the nitroalkane anions recorded in Table II were determined in 80% methanol using a model DK-1 Beckman spectrophotometer and 1-cm. stoppered silica absorption cells. The nitroalkane anion solutions were prepared under nitrogen as described above and diluted with 50 ml. of solvent at room temperature in the reactor. Aliquots of these solutions were further diluted and immediately examined. Since the density of each nitroalkane examined was within a few per cent. of unity, the concentrations of nitroalkanes employed were calculated on the assumption that the 0.003 ml. of nitroalkane introduced was equal to 3 mg. of material. For this reason the extinction coefficients may be accurate only to ±5%.

Reaction products were analyzed for regenerated nitroalkane by making a run as described above and withdrawing no aliquots. The reaction mixture was then warmed to room temperature, and 5 ml. of 19 N (saturated) sodium hydroxide solution was added under nitrogen. After 1 to 2 hr. the spectrum of the basic reaction mixture was scanned using suitably diluted 19 N sodium hydroxide in the solvent cell. Only nitrocyclobutane showed absorption in the 230 mμ region. In two such experiments with this compound, the concentration of nitroalkane present in the basic solution before acidification was such as to give an optical density reading at 234 mμ of 0.91 after suitable dilution. After the Nef reaction had been carried out, the optical density observed at 232–234 mμ was 0.16 when concentrations were normalized to that of the original nitroalkane anion solution. About one-sixth of the nitrocyclobutane either survived the Nef reaction or the reaction produced a small amount of strongly absorbing impurity.

Ketone Isolation Procedure.—One-half gram samples of each nitroalkane were dissolved in 4.0 ml. of 2.5 N sodium hydroxide in 80% methanol in the reactor under nitrogen and at room temperature. After 0.5 hr., 50 ml. of 80% methanol was added and the solution cooled to 0° for 0.5 hr. Exactly 3.0 ml. of 12 N hydrochloric acid was added and the solution was stirred for 0.5 hr. In every case examined, acidification led to the immediate formation of a blue color. In each case, except those of 1-cyclopropylnitroethane and dicyclopropylnitromethane, this blue color rapidly disappeared. In the two abnormal cases the blue color persisted and finally disappeared as pseudonitrole separated from solution. Filtration of these solutions afforded about 5–10 mg. of unstable white solid which turned blue on solution in warm methylene chloride. A control experiment showed that 1-nitrosonitrocyclohexane was stable under these reaction conditions and indicates that pseudonitroles would have been isolated if they had been produced in other cases.

In every case the reaction mixture was placed on the steam-bath and warmed to 60°. At this point a slurry of 1 g. of 2,4-dinitrophenylhydrazine in 100 ml. of 6 N hydrochloric acid was added and the solution stirred and heated for 20 minutes, cooled to room temperature and filtered. The crude crystalline derivatives were washed with warm water, dried, weighed and melting points determined. Table III summarizes the yield data.

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[CONTRIBUTION FROM ROHM AND HAAS CO., REDSTONE ARSENAL RESEARCH DIVISION]

aci-Nitroalkanes. III. The Solvolysis of α-Chloronitrosocycloalkanes in the Presence of Electrophilic Silver Ion

BY M. FREDERICK HAWTHORNE AND R. DONALD STRAHM

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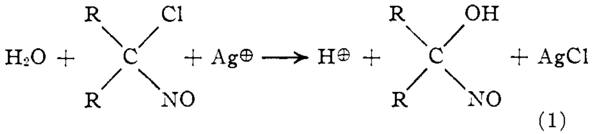
1-Chloronitrosocyclohexane and 1-chloronitrosocyclopentane are rapidly converted to cyclohexanone and cyclopentanone, respectively, in essentially quantitative yields when treated with silver perchlorate in 20:30:50 (by volume) ethanol: water:acetonitrile at 50.0°. The rates of these reactions were determined under the above conditions by titration of liberated hydrogen ion. The rate equation in each case is of the form $d[H^+]/dt = k[Ag^+]$[chloronitrosocycloalkane] with the second-order rate constant, k, equal to 2.0 and 5.0×10^{-2} l. mole^{-1} min.$^{-1}$ for 1-chloronitrosocyclohexane and 1-chloronitrosocyclopentane, respectively. No hydroxylamine, nitrogen, nitric oxide or nitrogen dioxide was produced and nitrous oxide was identified by gas chromatography. Silver chloride is produced in quantitative yield. It is suggested that these transformations probably proceed *via* the α-hydroxynitrosocycloalkanes which are in turn produced by the nucleophilic attack of water upon the α-carbon atom. This proposed path is in accord with recent proposals concerning the mechanism of the Nef reaction.

Because of our previous interest in the mechanism of the Nef reaction[1] and the probable relationship of the chemistry of α-hydroxynitrosoalkanes to that reaction, it was of interest to seek a more direct route to such materials and to determine their mode of decomposition in acidic aqueous media.

Piloty and Stock[2] long ago reported the synthesis of 2-nitro-2-nitrosopropane by the reaction of silver nitrite with 2-bromo-2-nitrosopropane in ethereal solution. This silver ion assisted displacement of bromide ion by nitrite ion probably proceeded by way of a concerted termolecular displacement reaction such as those recently characterized by Kornblum and Hardies[3] and by Hammond and Hawthorne.[4] It thus appeared probable that the similar treatment of 1-chloronitrosoalkanes with silver ion in the presence of water and in the absence of nucleophilic anions might yield α-hydroxynitrosoalkanes.



$$H_2O + R_2C(Cl)(NO) + Ag^{\oplus} \longrightarrow H^{\oplus} + R_2C(OH)(NO) + AgCl \qquad (1)$$

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(1) M. F. Hawthorne, THIS JOURNAL, **79**, 2510 (1957).

(2) O. Piloty and A. Stock, *Ber.*, **35**, 3093 (1902).

(3) N. Kornblum and D. E. Hardies, Abstracts of the 130th Meeting of the American Chemical Society, September 16 to 21, 1956, Atlantic City, N. J., p. 2-O.

(4) G. S. Hammond and M. F. Hawthorne, Abstracts of the 126th Meeting of the American Chemical Society, New York, N. Y., September 12 to 17, 1954, p. 41-O.