Decarboxylation of the half-ester IV and measuring the O^{18} content of the liberated carbon dioxide seem the most direct route to determine the isotopic composition of the carboxylic acid group of the half-ester. To this end a sample (± 200 mg.) of the half-ester was heated at 240–250° during 15 min. in a sealed, evacuated, small Pyrex tube, which had an extended point on one side. The Pyrex tube was cooled and connected with this pointed end to a high-vacuum apparatus by a rubber vacuum tube. The apparatus was evacuated, the Pyrex tube was cooled in a mixture of Dry Ice and acetone, the pointed end of the Pyrex tube was broken in the rubber tube, and finally the carbon dioxide was collected in a sample trap immersed in liquid nitrogen.

This sample of carbon dioxide proved to be contaminated by some gaseous impurities. It was purified by the elegant method of Ehrensvärd.[19] A 0.75% solution of octadecylamine in dry petroleum

(19) G. Ehrensvräd, Z. Naturforsch., 14b, 607 (1959).

ether (b.p. 80–100°) was leaked into the sample trap and the carbon dioxide precipitated as the carbamate. The latter was isolated by centrifugation and drying in vacuo over silica gel. As the carbamate decomposed within several minutes by heating at 100°, the carbon dioxide was recovered by essentially the same procedure as described above for the decarboxylation of the half-ester. The carbon dioxide thus obtained proved to be mass spectrometrically pure.

Three samples of benzil as well as three samples of carbon dioxide, obtained by decarboxylation of the half-ester IV, were analyzed for their O^{18} content. Mass spectrometric analyses gave the following results. *Anal.* Found for benzil: 1.16, 1.15, 1.19 (average, 1.17% O^{18}). Found for CO_2: 0.61, 0.59, 0.56; (average, 0.59% O^{18}).

The Action of Acids on Nitronic Esters and Nitroparaffin Salts. Concerning the Mechanisms of the Nef and the Hydroxamic Acid Forming Reactions of Nitroparaffins[1,2]

Nathan Kornblum and R. Alan Brown

Contribution from the Department of Chemistry, Purdue University, Lafayette, Indiana. Received November 20, 1964

Nitronic esters are rapidly decomposed by acids; the course which the reaction follows is strongly dependent on the acid concentration. Thus, the ethyl nitronic ester of p-nitrophenylnitromethane gives p-nitrobenzaldehyde in 80% yield on treatment with 4 N sulfuric acid while, in contrast, 31 N sulfuric acid converts it into p-nitrobenzhydroxamic acid in 98% yield. The reaction of nitroparaffin salts with sulfuric acid also exhibits this dependence on acid concentration. The mechanisms of these new nitronic ester reactions, and of the Nef and the hydroxamic acid forming reactions of nitroparaffins, are discussed in the light of these facts.

The salts of primary nitroparaffins when treated with aqueous mineral acid are smoothly converted to aldehydes. This reaction, known as the Nef Reaction, is of considerable synthetic value[3] (eq. 1).

$$[RCHNO_2]^- Na^+ \xrightarrow[H^+]{H_2O} RCHO + N_2O \qquad (1)$$

However, when primary nitroparaffins (rather than their salts) are treated with hot, concentrated mineral acid, the corresponding carboxylic acids and hydroxylamine are produced, hydroxamic acids being intermediate (eq. 2). The yields are usually excellent and

$$RCH_2NO_2 \xrightarrow{H^+} R\underset{\underset{OH}{|}}{C}{=}NOH \longrightarrow RCOOH + H_2NOH \qquad (2)$$

since the reaction was first observed by Victor Meyer his name is sometimes attached to it.[4]

Protonation of a nitroparaffin salt occurs preferentially at oxygen to give the *aci* structure I. Not surprisingly, it is generally agreed that the Nef reaction proceeds by way of the *aci* form of the nitroparaffin I.[5] But, as Noland has pointed out,[3c] there is reason

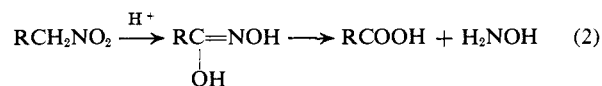$$RCH{=}\overset{+}{N}\overset{\displaystyle O^-}{\underset{\displaystyle OH}{\diagup}}$$

I

(1) This work was supported by the Air Force Office of Scientific Research, Office of Aerospace Research, United States Air Force, under AFOSR Grant No. 122–65.

(2) Paper XXII in the series, "The Chemistry of Aliphatic and Alicyclic Nitro Compounds." For the preceding paper see N. Kornblum and R. A. Brown, J. Am. Chem. Soc., 85, 2681 (1963).
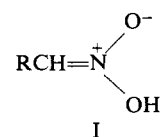
(3) (a) J. U. Nef, Ann., 280, 264 (1894); (b) J. C. Sowden, "Advances in Carbohydrate Chemistry," Vol. 6, Academic Press Inc., New York, N. Y., 1951, pp. 291–318; (c) W. E. Noland, Chem. Rev., 55, 136 (1955).

(4) V. Meyer and C. Wurster, Ber., 6, 1168 (1873); E. Bamberger and E. Rüst, ibid., 35, 45 (1902); S. B. Lippincott and H. B. Hass, Ind. Eng. Chem., 31, 118 (1939); M. J. Kamlet, L. A. Kaplan, and J. C. Dacons, J. Org. Chem., 26, 4371 (1961).

(5) W. E. Noland, ref. 3c; E. E. van Tamelen and R. J. Thiede, J.

to believe that the conversion of primary nitroparaffins to carboxylic acids and hydroxylamine also goes by way of the *aci* structure I. Thus the interesting question arises, what controls the fate of the *aci* form I?

Although the literature is less than explicit concerning the matter of acidity, it seems to be a reasonable assumption that the mode of degradation which the *aci* form I undergoes is a function of the acidity of the reaction medium. Actually, this possibility has been recognized by previous workers, in particular by Noland,[3e] but hitherto the matter has not been subjected to a direct experimental test. The present paper reports the results of two such tests: (1) a study of the consequences of changes in acid strength on the course of the reaction of acids with nitroparaffin salts (*i.e.*, on the course of the "Nef" reaction), and (2) a study of the action of acids on nitronic esters II.

$$RCH=\overset{+}{N}\overset{O^-}{\underset{OC_2H_5}{\diagup}}$$

II

The reactions of the nitronic esters II are of special importance since these compounds are, in essence, a "frozen" form of the *aci* structure I. With nitronic esters, in contrast to *aci*-nitro compounds, tautomerization cannot occur so that an experimental complication, and a source of ambiguity in discussing the matter of mechanism, is removed.

The p-Nitrophenylnitromethane System. The action of cold, dilute, aqueous acid on the salt of a nitro compound either regenerates the nitro compound[6] or, at the other extreme, results in aldehyde formation (eq. 1). Many salts fall in between these two extremes; in part they are converted back to the nitro compound and, in part, they go to aldehyde. The Nef reaction occurs most readily on acidification of the salts of simple aliphatic and alicyclic nitroparaffins whereas with systems possessed of considerable resonance stabilization reaction occurs with difficulty, or not at all.[7]

It is not surprising, then, that the sodium salt of *p*-nitrophenylnitromethane when treated with 2 *N* aqueous sulfuric acid gives a precipitate consisting of *p*-nitrophenylnitromethane and its *aci* tautomer[8] (96% yield); furthermore, *p*-nitrobenzaldehyde cannot be detected in the reaction product. This failure to undergo the Nef reaction is not a consequence of the insolubility of the *aci* and true nitro forms of *p*-nitrophenylnitromethane, for, when an aqueous solution of the sodium salt of *p*-nitrophenylnitromethane is added to sulfuric acid in aqueous 1,2-dimethoxyethane, and the resulting clear solution (3.5 *N* in acid) is allowed to stand for 45 min., a 93% yield of pure *p*-nitrophenylnitromethane is recovered. Significantly, the *p*-nitrophenylnitromethane is free of the *aci* tautomer.[9]

Am. Chem. Soc., **74**, 2615 (1952); L. C. Leitch, *Can. J. Chem.*, **33**, 400 (1955); M. F. Hawthorne, *J. Am. Chem. Soc.*, **79**, 2510 (1957); H. Feuer and A. T. Nielsen, *ibid.*, **84**, 688 (1962).

(6) Protonation occurs preferentially (but not exclusively) at oxygen but the resulting *aci* form readily dissociates and by slow, but essentially irreversible, protonation at carbon the true nitro compound is produced.

(7) N. Kornblum and G. E. Graham, *J. Am. Chem. Soc.*, **73**, 4041 (1951).

(8) This mixture was quantitatively converted to pure *p*-nitrophenylnitromethane with a potassium acetate–acetic acid buffer (*cf.* Experimental).

Clearly, the Nef reaction has lost out in competition with isomerization of the reactive *aci* form to the unreactive true nitro structure.

In contrast, with 85% sulfuric acid (31 *N*) a reaction occurs readily, but it is not the Nef reaction. On exposure to sulfuric acid of this strength for a few minutes at room temperature the sodium salt of *p*-nitrophenylnitromethane is converted into *p*-nitrobenzhydroxamic acid (III) in 86% yield.[10,11]

$$O_2N-\!\!\!\!\diagdown\!\!\!\!\diagdown\!\!\!\!-\overset{\overset{O}{\parallel}}{C}-NHOH$$

III

The most dramatic (and instructive) demonstration of the importance of the proton donating capability of the acid employed is provided by nitronic ester IV.[12] Treatment of this nitronic ester with dilute (*ca.* 4 *N*)

$$O_2N-\!\!\!\!\diagdown\!\!\!\!\diagdown\!\!\!\!-CH=\overset{+}{N}\overset{O^-}{\underset{OC_2H_5}{\diagup}}$$

IV

sulfuric acid at room temperature gives *p*-nitrobenzaldehyde in 80–82% yield and *p*-nitrobenzhydroxamic acid (III) in 6% yield. In contrast, with 85% sulfuric acid (31 *N*) *p*-nitrobenzaldehyde cannot be detected and the hydroxamic acid III is isolated in 98% yield.[13] Thus, with the "frozen" *aci* structure on going from dilute to concentrated sulfuric acid a complete overturn in reaction course results and, by clear implication, whether the Nef reaction (eq. 1) or the alternative reaction of eq. 2 will be favored is a function of the proton donating capability of the acid to which the

Chart I. The Importance of the Acid Concentration

(9) A trace of *p*-nitrobenzaldehyde may have been formed but, in any event, the yield is no more than 0.5% (*cf.* Experimental).

(10) The product actually is a mixture of the pure hydroxamic acid (71% yield) and *p*-nitrophenylnitromethane (21% recovery). Furthermore, it was shown in a separate experiment that *p*-nitrophenylnitromethane is stable to 85% sulfuric acid at room temperature.

(11) The closest analog of this result is the work of E. Bamberger and E. Rust, *Ber.*, **35**, 45 (1902). They obtained very small amounts of hydroxamic acids on treating the sodium salts of nitroethane, 1-nitropentane, and phenylnitromethane with dilute aqueous hydrochloric acid, but, perhaps significantly, they were not able to detect any hydroxamic acid when the sodium salt of 3,5-dimethylphenylnitromethane was treated with 2 *N* aqueous sulfuric acid (*cf.* footnote 14).

(12) The relatively stable, higher melting stereoisomer was employed (*cf.* ref. 2).

(13) Several experiments were conducted at intermediate acidities. With 50% sulfuric acid, IV gives a 71% yield of the hydroxamic acid III and a small amount of *p*-nitrobenzoic acid. Treatment of nitronic ester IV with 30% sulfuric acid produces the hydroxamic acid in 24% yield, *p*-nitrobenzoic acid in *ca.* 30% yield, and the oxime of *p*-nitrobenzaldehyde in 22% yield.

Table I. Reactions of Nitroparaffin Salts with Sulfuric Acid

Salt	Products with dilute H₂SO₄ (%)	Products with 85% H₂SO₄ (%)
p-BrC₆H₄CHNO₂⁻Na⁺	p-BrC₆H₄CH₂NO₂ (90)[a]	p-BrC₆H₄CONHOH (29)
CH₃CHNO₂⁻Na⁺	CH₃CHO (85) / CH₃CONHOH (2)[b]	CH₃CONHOH (45)
CH₃CH₂CH₂CHNO₂⁻Na⁺	CH₃CH₂CH₂CHO (70) / CH₃CH₂CH₂CONHOH (4)[b]	CH₃CH₂CH₂CONHOH (56)[c]

[a] With 10% H₂SO₄. [b] With 21% H₂SO₄. [c] Actually 28%; 50% recovery of 1-nitrobutane.

Table II. Reactions of Nitronic Esters with Sulfuric Acid

Nitronic ester	Products with dilute H₂SO₄ (%)	Products with 85% H₂SO₄ (%)
p-BrC₆H₄CH=NO₂C₂H₅	p-BrC₆H₄CHO (65) / p-BrC₆H₄CONHOH (12)	p-BrC₆H₄CONHOH (63)
CH₃CH=NO₂C₂H₅	CH₃CHO (67)	CH₃CONHOH (41)
CH₃CH₂CH=NO₂C₂H₅	CH₃CH₂CHO (good)	
(CH₃)₂C=NO₂C₂H₅	(CH₃)₂CO (72)	
CH₃CH₂CH₂CH=NO₂C₂H₅	CH₃CH₂CH₂CHO (good)	CH₃CH₂CH₂CONHOH (42)
CH₃CH₂CCH₃ ‖ NO₂C₂H₅	CH₃CH₂COCH₃ (81)	

aci form I is exposed.[14] Chart I summarizes our results.

Several other systems have been examined in a somewhat less thorough manner than the *p*-nitrophenylnitromethane system. One difficulty is that the nitronic esters derived from other nitro compounds are less stable thermally than IV[2] and, in consequence, side reactions compete with the acid-catalyzed processes to a significant degree. In any event, while the material balances are not as good, the results clearly accord with those obtained in the *p*-nitrophenylnitromethane system (*cf.* Tables I and II).

While the results reported in this paper do not provide a basis for describing, in a precise way, the mechanisms of the Nef and the hydroxamic acid forming reactions, they do provide valuable insights. For one thing, it is clear that the protonated nitronic ester, and hence the protonated *aci*-nitroparaffin, is an intermediate in the Nef reaction, a conclusion which has previously been reached on kinetic grounds by Hawthorne.[5] Furthermore, it is apparent that hydroxamic acid formation must also proceed *via* the same protonated nitronic ester (and hence *via* the same protonated *aci*-nitroparaffin) as the Nef reaction. Finally, it is especially significant that the production of hydroxamic acid is favored by an increase in the proton donating capacity of the system. Chart II provides a rationale for these facts. The proposed mechanisms can only be regarded as suggestive rather than definitive, for a number of variations in the latter stages are readily envisioned and it is, at present, not possible to make a choice between them.

Experimental[15]

All melting and boiling points are uncorrected. Infrared spectra were recorded on a Perkin-Elmer

(14) With acids whose anions are good nucleophiles the situation becomes clouded by the competition between water and the anion for the *aci*-nitroparaffin (or nitronic ester). For example, with aqueous hydrochloric acid, hydroxamic acid chlorides, RC(Cl)=NOH, are produced; F. Arndt and J. D. Rose, *J. Chem. Soc.*, 1 (1935) (also see Experimental).

Chart II. Mechanisms For The Nef and Victor Meyer Reactions

$$R-C(H)=\overset{+}{N}(O^-)(OR') \xrightarrow{H^+}$$

$$\left[R-\overset{H}{C}=\overset{+}{N}(OH)(OR') \longleftrightarrow R-\overset{H}{C}-\overset{\cdot\cdot}{\overset{+}{N}}(OH)(OR') \right]$$

$$\xrightarrow{H_2O} \; R-\overset{H}{\underset{+OH_2}{C}}-\overset{\cdot\cdot}{N}(OR')-OH$$

$$\xrightarrow{H^+} \; R-\overset{H}{\underset{+OR'}{C}}-\overset{\cdot\cdot}{N}-OH \quad \overset{+OR'}{\underset{H}{}}$$

$$\downarrow$$

$$R-\overset{H}{\underset{OH}{C}}-\overset{\cdot\cdot}{N}(+OR')-OH \quad \downarrow H$$

$$\downarrow$$

$$R-\overset{H}{\underset{OH}{C}}-N=O + R'OH + H^+$$

$$\downarrow$$

$$RCHO + N_2O + H_2O$$

$$\xrightarrow{-R'OH}$$

$$\left[R\overset{H}{C}-\overset{\cdot\cdot}{\overset{+}{N}}-OH \longleftrightarrow R-\overset{H}{\overset{+}{C}}-\overset{\cdot\cdot}{N}=OH \right]$$

$$\xrightarrow{-H^+} \; R-C\equiv\overset{+}{N}-OH$$

$$\xrightarrow{H_2O} \; RC-NHOH + H^+$$
$$\;\;\;\;\;\; \overset{\|}{O}$$

R' = H or C₂H₅
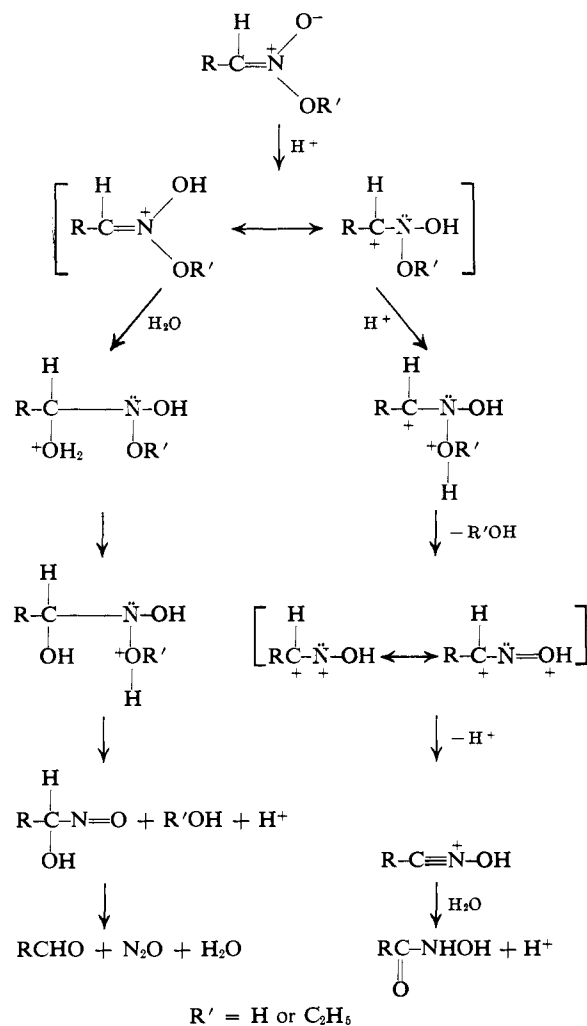
Model 21 or 221 spectrophotometer; liquids were run neat and solids as Nujol or fluorolube mulls. All

(15) Analyses by Dr. C. S. Yeh, Purdue University, and Galbraith Microanalytical Laboratories, Knoxville, Tenn.

solvents were dried and then distilled through a short column.

The nitronic esters, nitro compounds, and nitro salts were prepared as described earlier.[2] The ethyl nitronic ester of p-nitrophenylnitromethane used was the predominant isomer, m.p. 100–101°; the other nitronic esters were cis–trans mixtures.[2]

Authentic p-nitrobenzhydroxamic acid was prepared according to Holleman.[16] The white product melts at 172–174° with gas evolution and then resolidifies at 176–178° (bath preheated to 165°). Its infrared spectrum is identical with the published spectrum[17] and, when dissolved in 50% ethanol–50% water which is 0.1 N in HCl, it exhibits λ_{max} 269 mμ (ϵ_{max} 11,100), lit.[18] λ_{max} 268 mμ (ϵ_{max} 11,180) in the same solvent. It dissolves (yellow solution) in 10% sodium bicarbonate and gives an intense purple-violet color when dissolved in ethanol and treated with aqueous ferric chloride. An analytically pure sample of p-nitrobenzhydroxamic acid was prepared by continuous extraction of the 172–174° melting material with ethyl ether; after about half of the hydroxamic acid had been extracted, evaporation of the ether gave fluffy white needles, m.p. (165° preheat) 176.2–177° with gas evolution and then resolidification at 178–179°.

Anal. Calcd. for $C_7H_6N_2O_4$: C, 46.16; H, 3.32; N, 15.38. Found: C, 46.43; H, 3.47; N, 15.20.

Reactions of the Sodium Salt of p-Nitrophenylnitromethane. A. With 2 N Aqueous Sulfuric Acid. The dry, powdered salt (1.00 g., 4.90 mmoles) was added over a 2-min. period to 25 ml. of vigorously stirred 2 N sulfuric acid at 0 to 3°. After addition, the mixture was maintained at 27° for 0.5 hr. and then 75 ml. of ice water was added. After stirring in an ice bath for 5 min., the mixture was filtered and the solid was washed with a total of 35 ml. of cold water. (The combined aqueous solutions were labeled A.) The solid was dried for 3 hr. *in vacuo* over phosphorus pentoxide; the yield of nitro and *aci*-nitro compounds was 0.83 g. (93%), m.p. 76–82°. By means of an acetate buffer[19] this was converted to pure p-nitrophenylnitromethane in 99% yield, m.p. 90.2–91.5°; a mixture with an authentic sample (m.p. 91.2–92.0°) melted at 91.0–92.0°. The infrared spectrum of the product was identical with that of an authentic sample.

Aqueous solution (A) was extracted with benzene and the benzene was washed with water until the pH of the wash was 4. Upon drying and vacuum evaporating the benzene, there resulted an additional 0.025 g. (3%) of pale yellow nitro compound, m.p. 87–88.7°. The crude product, m.p. 76–82°, on treatment with 2,4-dinitrophenylhydrazine reagent (2,4-DNP) gave no precipitate.

B. With 3.5 N Sulfuric Acid in Aqueous 1,2-Dimethoxyethane (Homogeneous). A solution prepared by diluting 33.1 ml. of cold, 50% sulfuric acid to a volume of 122 ml. with 1,2-dimethoxyethane was cooled to 5° and to it was added, dropwise, with stirring, in 2 min., a solution containing 1.00 g. (4.90

mmoles) of the sodium salt of p-nitrophenylnitromethane in 10 ml. of water. The solution was then held at 22° for 45 min., after which it was treated with 100 ml. of water and evaporated *in vacuo* for 4 hr. at 20–30°; toward the end the temperature was briefly raised to 50°. The slurry was ice cooled, filtered, and washed with cold water. Vacuum drying gave 0.830 g. (93%) of p-nitrophenylnitromethane, m.p. 90.8–91.3°, whose infrared spectrum was identical with that of an authentic sample. On treatment of the aqueous mother liquor with 2,4-DNP reagent nothing happened in 1 hr. After standing overnight 0.01 g. of an orange solid, m.p. 298–308°, which may be the impure 2,4-DNP of p-nitrobenzaldehyde, was obtained.

C. With 85% Sulfuric Acid (31 N). One gram of the dry, powdered salt was added in 1 min. to 15 g. of ice-cooled, stirred, 85% sulfuric acid. The mixture was warmed to 25° in 15 min. while stirring and then poured onto 90 g. of ice. The precipitate was washed with cold water and dried *in vacuo*. The combined aqueous solutions were labeled (A). The 0.625 g. of solid was washed with two 10-ml. portions of benzene; evaporation of the benzene gave 0.185 g. of crude p-nitrophenylnitromethane, m.p. 87–140° (most by 90°). A 0.155-g. portion was chromatographed on acid alumina (Merck) in benzene. This gave 0.15 g. (21% recovery) of pure nitro compound, m.p. 90–91°. The benzene-insoluble white powder (0.440 g.) was pure p-nitrobenzhydroxamic acid (49% yield), m.p. and m.m.p. 176.5–177.5°, the infrared spectrum being identical with that of an authentic sample.

Anal. Calcd. for $C_7H_6N_2O_4$: C, 46.16; H, 3.32; N, 15.38. Found: C, 46.14; H, 3.44; N, 15.25.

Aqueous solution A was extracted with benzene and then treated with cold 30% aqueous sodium hydroxide until the pH was 4.5. After vacuum evaporation (below 55°), Soxhlet ether extraction of the residue gave another 0.19 g. (22% yield) of p-nitrobenzhydroxamic acid, m.p. 175–175.5°.

Recovery of p-Nitrophenylnitromethane from 85% Sulfuric Acid. The nitro compound (0.670 g.), m.p. 91.0–91.8°, was added to 15 g. of ice-cold 85% sulfuric acid and then stirred under nitrogen for 3.5 hr. at 25°. The nitro compound was recovered by pouring onto ice, yield 0.64 g. (96%), m.p. and m.m.p. 91.0–91.7°.

Reactions of the Ethyl Nitronic Ester of p-Nitrophenylnitromethane. A. With Dilute Sulfuric Acid. The ethyl nitronic ester of p-nitrophenylnitromethane (3.0 g., 14.3 mmoles) was added, in 1 min., to 60 ml. of 3.12 N sulfuric acid with ice cooling and stirring. (The acid was *ca.* 10% by volume water, *ca.* 81% by volume ethanol, and *ca.* 9% by volume sulfuric acid.) The stirred slurry was held at 0° under nitrogen for 1.3 hr. and then at 25° for 18 hr. The solution was then cooled to 0° and added to 90 g. of ice. The product was ether extracted and the ether phase was washed with 10% aqueous sodium bicarbonate. These washes were added to the aqueous phase and the solution was brought to pH 4.5 and vacuum evaporated to dryness. Soxhlet ether extraction of the residue gave 0.18 g. of yellow solid; this was washed well with benzene leaving 0.17 g. (6% yield) of p-nitrobenzhydroxamic acid, m.p. 171–172°, whose infrared spectrum was identical with that of an authentic sample, and which gave a violet color with ferric chloride.

(16) A. F. Holleman, *Rec. trav. chim.,* **16,** 186 (1897).
(17) "Sadtler Standard Spectra Catalog," The Sadtler Laboratories, Philadelphia, Pa., 1962, spectrum 8135.
(18) R. E. Plapinger, *J. Org. Chem.,* **24,** 802 (1959).
(19) H. E. Zimmerman and T. E. Nevins, *J. Am. Chem. Soc.,* **79,** 6559 (1957); W. F. Trager, F. F. Vincenzi, and A. C. Huitric, *J. Org. Chem.,* **27,** 3006 (1962).

Anal. Calcd. for $C_7H_6N_2O_4$: C, 46.16; H, 3.32; N, 15.38. Found: C, 46.38; H, 3.36; N, 15.46.

The bicarbonate-washed ether solution was washed with water, dried, and evaporated to give 2.60 g. of yellow oil. This was treated with 2,4-DNP reagent and the precipitate was isolated, washed with 95% ethanol, and dried *in vacuo*. The 4.0 g. (82% yield) of *p*-nitrobenzaldehyde 2,4-DNP had m.p. 308–310° and did not depress the melting point of authentic material.

Anal. Calcd. for $C_{13}H_9N_5O_6$: N, 21.15. Found: N, 21.17.

When the nitronic ester was treated with 4.96 *N* aqueous ethanolic sulfuric acid (*ca.* 9% by volume water) for 14.5 hr. at 25°, an 80% yield of the 2,4-DNP of *p*-nitrobenzaldehyde and a 5% yield of somewhat impure *p*-nitrobenzhydroxamic acid were obtained.

That the acid was indeed causing aldehyde formation was shown by the following experiment. The nitronic ester (0.20 g.) was dissolved in 30 ml. of 95% ethanol. After 17.5 hr. at 25°, the solution was treated with 2,4-DNP; only after 7 min. did the solution become cloudy, and only after *ca.* 25 min. did 0.005 g. (1% yield) of precipitate form. In contrast, when the 95% ethanol solution was 1.3 *N* in sulfuric acid, and the solution was allowed to stand for 18 hr., a 54% yield of *p*-nitrobenzaldehyde 2,4-DNP was obtained on 5-min. treatment with the reagent.

B. With 85% Sulfuric Acid. The powdered ester (0.60 g., 2.85 mmoles) was added in 1 min. to 15 g. of ice-cooled, stirred, 85% sulfuric acid. After flushing with nitrogen, the flask was stoppered and warmed to 25°. After 60 min. the solution was added to 90 g. of ice. The solid was washed with 40 ml. of cold water and dried, yielding 0.305 g. of *p*-nitrobenzhydroxamic acid. More was obtained from the combined aqueous solutions by adjusting the pH to 4.5, vacuum evaporating to dryness at 50°, and extracting with ether (Soxhlet), yield 0.205 g. (total 98% yield). Both crops melted at 174–175°; the mixture melting point was undepressed. The infrared and ultraviolet spectra were identical with those of authentic material.

Anal. Calcd. for $C_7H_6N_2O_4$: C, 46.16; H, 3.32; N, 15.38. Found: C, 46.29; H, 3.34; N, 15.30.

A run carried out for 29 hr. at 25°, under nitrogen, gave a 92% yield of *p*-nitrobenzhydroxamic acid.

Reaction of the Ethyl Nitronic Ester of p-Bromophenylnitromethane with 85% Sulfuric Acid. The ice-cold ester (2.71 g., 11.1 mmoles) was added dropwise to 16.61 g. of ice-cooled, stirred 85% sulfuric acid, temperature below 20°. After an additional 8 min. of stirring the slurry was poured on 100 g. of ice and filtered. The solid was washed with 50 ml. of cold water, dried, and washed with benzene and ether. The 1.63 g. of white, insoluble solid was purified by continuous ether extraction; the first extract yielded 0.05 g. of a brown-tan powder, m.p. 152°, which was not further examined. Further extraction gave lustrous, tan plates of *p*-bromobenzhydroxamic acid, m.p. 189.5–190° with gas evolution and resolidification at 191.5–193° (bath preheated to 176°), yield 1.57 g. (63%). The product gave an intense violet-purple color when dissolved in alcohol and treated with 5% aqueous ferric chloride.

Anal. Calcd. for $C_7H_6BrNO_2$: C, 38.92; H, 2.80;

Br, 36.99; N, 6.48. Found: C, 38.86; H, 2.80; Br, 37.18; N, 6.41.

Reaction of the Ethyl Nitronic Ester of p-Bromophenylnitromethane with 1.8 N Sulfuric Acid. The nitronic ester (1.00 g., 4.10 mmoles) was dissolved in 95% ethanol (65 ml.) at room temperature and immediately treated with 35 ml. of 2,4-DNP reagent.[20] The resulting clear solution was 1.8 *N* in sulfuric acid, 0.041 *M* in ester, 0.050 *M* in 2,4-DNP, and contained about 84% by volume of ethanol. Soon after mixing, precipitation began and after 30 min. at 30° the 2,4-DNP of *p*-bromobenzaldehyde was isolated, yield 0.825 g. (55%), m.p. 245–247°. From the mother liquor, an additional 20% yield was obtained, m.p. 241–245°, after 17 hr. A parallel experiment in which 2,4-DNP was absent gave a 12% yield of pure *p*-bromobenzhydroxamic acid after 12 hr.

Reaction of the Sodium Salt of p-Bromophenylnitromethane with 85% Sulfuric Acid. The dry, powdered salt (1.92 g.) was added in 9 min. to 15 ml. of ice-cooled, stirred, 85% sulfuric acid at 7 to 8°. After stirring for an additional 5 min. the slurry was poured onto ice and worked up in the usual way. A 0.495-g. yield (29%) of *p*-bromobenzhydroxamic acid, m.p. 190–190.5°, was obtained.

Anal. Calcd. for $C_7H_6BrNO_2$: C, 38.92; H, 2.80; Br, 36.99; N, 6.48. Found: C, 39.05; H, 2.85; Br, 37.24; N, 6.56.

This product has an infrared spectrum identical with that of the compound produced on treatment of the ethyl nitronic ester with 85% sulfuric acid (*vide supra*).

p-Bromophenylnitromethane was recovered quantitatively after treatment with 85% sulfuric acid at 0° for 2.5 hr.

Reaction of the Sodium Salt of p-Bromophenylnitromethane with 10% Sulfuric Acid. The dry, powdered salt (3.45 g.) was added in 2 min. to 25 ml. of stirred, 10% sulfuric acid kept at 1 to 2°. After 3 more min. of stirring the slurry was diluted with 25 ml. of ice-cold water; the solid was isolated by filtration, washed with ice-cold water, and dried over phosphorus pentoxide *in vacuo*. The white powder (2.84 g., 90% yield) melted at 54.9 to 56° to give a slightly cloudy melt which only became clear at 140°. In our hands the pure nitro compound has m.p. 55–56°; (lit. m.p. 56–57°[21] and 60°[22]). Ether extraction of the combined aqueous solutions gave 0.09 g. of solid which gave no precipitate with 2,4-DNP reagent.

Reaction of the Sodium Salt of 1-Nitrobutane with 85% Sulfuric Acid. The dry, powdered salt (24.9 g.) was added, in 1 hr., to 140 g. of stirred 85% sulfuric acid at 7 to 9°. The slurry was then added, in 3 min., to 600 g. of ice. With ice cooling, ice-cold 30% sodium hydroxide was added so as to raise the pH to 4 (temperature 10 to 15°) and then 100 ml. of water was added. The mixture was extracted with pentane, and from the extracts, a 50% yield of 1-nitrobutane, $n^{20}D$ 1.4110, was obtained.

The aqueous solution was vacuum evaporated to dryness and ether extracted (Soxhlet); this gave 6.5 g.

(20) R. L. Shriner, R. C. Fuson, and D. Y. Curtin, "The Systematic Identification of Organic Compounds," 4th Ed., John Wiley and Sons, Inc., New York, N. Y., 1956, p. 111.
(21) W. Wislicenus and A. Endres, *Ber.*, **35**, 1755 (1902).
(22) A. Hantzsch and O. W. Schultze, *ibid.*, **29**, 2251 (1896).

(28% yield) of a viscous oil. The oil had an intense band at 5.9 to 6.2 μ, and gave an intense purple-red color with ferric chloride; cupric acetate solution (containing a little potassium acetate) gave a green precipitate. On standing, this oil crystallized, m.p. 40.8–42°. Recrystallization from ethyl acetate–petroleum ether (b.p. 35°) at −50° gave a white powder, m.p. 43–44° (lit.[23] 42–43°). This hydroxamic acid is quite hygroscopic.

Anal. Calcd. for $C_4H_9NO_2$: C, 46.59; H, 8.80; N, 13.59. Found: C, 46.32; H, 8.63; N, 13.63.

Reaction of the Sodium Salt of 1-Nitrobutane with Dilute Sulfuric Acid. This was carried out according to Johnson and Degering.[24] A 78% yield of the 2,4-DNP of 1-butanal, m.p. 102–104.5°, was obtained. In addition, a 4% yield of *n*-butyrohydroxamic acid was isolated as a yellow oil whose infrared spectrum was identical with that of the authentic sample (*vide supra*).

Reaction of the Ethyl Nitronic Ester of 1-Nitrobutane with 85% Sulfuric Acid. The ester (0.74 g.) was added dropwise (in 4 min.) to 15 g. of ice-cooled, stirred, 85% sulfuric acid; the temperature was *ca.* 10° except for a brief period at 17°. The resulting clear, colorless solution was stirred for another 3 min. at *ca.* 5° and then poured onto 70 g. of ice. Working up in the usual way gave 0.24 g. (42% yield) of *n*-butyrohydroxamic acid, showing an intense violet color with ferric chloride. The infrared spectrum was identical with that of the analytically pure specimen (*vide supra*).

Reaction of the Ethyl Nitronic Ester of 1-Nitrobutane with Dilute Sulfuric Acid. About 0.05 g. of the ester in 95% ethanol was treated with the 2,4-DNP reagent[20]; 13 sec. later a voluminous precipitate formed. This 2,4-DNP of 1-butanal had m.p. 105.5–107°; a mixture melting point with an authentic sample (m.p. 107–107.5°) was 106–107°. Its infrared spectrum was identical with that of the authentic sample.

Reaction of the Ethyl Nitronic Ester of Nitroethane with Dilute Sulfuric Acid. The ester (2.18 g., 20.9 mmoles) in 40 ml. of 95% ethanol was treated at 25° with 180 ml. of the 2,4-DNP reagent.[20] In about 5 sec. a voluminous precipitate of the 2,4-DNP of acetaldehyde formed. After adding 180 ml. of water and storing for 9 hr., the mixture was ice cooled and filtered. The precipitate was washed with 150 ml. of 38% ethanol and with water, and then dried *in vacuo*, yield 3.14 g. (67%), m.p. 144–144.5°.

Anal. Calcd. for $C_8H_8N_4O_4$: C, 42.86; H, 3.60; N, 24.99. Found: C, 42.70; H, 3.92; N, 25.02.

Reaction of the Ethyl Nitronic Ester of Nitroethane with 85% Sulfuric Acid. The ester (2.575 g., precooled to 0°) was added in 11 min. to 36 g. of stirred, ice-cooled, 85% sulfuric acid at 6 to 8° (reaction highly exothermic). The solution was stirred for 3 min. and then poured onto 150 g. of ice. The mixture was treated with ice-cold 30% sodium hydroxide to bring the pH to 3.5 while the solution was kept below 18°. The solution was treated with 8 g. of potassium acetate to bring the pH to 6.3 and 5.0 g. of cupric acetate monohydrate in 100 ml. of water was added. This gave a

voluminous green precipitate of the copper salt of acetohydroxamic acid. After filtering and washing with water, the salt was dried *in vacuo* over phosphorus pentoxide. The 1.085 g. of green powder represented a 41% yield of acetohydroxamic acid. The infrared spectrum of the salt was identical with that of an authentic sample.

Reaction of the Sodium Salt of Nitroethane with 85% Sulfuric Acid. The dry, powdered salt (9.09 g.) was slowly added to 75 g. of ice-cooled, magnetically stirred 85% sulfuric acid in 37 min., temperature 10 to 14°. On working up, acetohydroxamic acid was isolated as its copper salt, yielding 4.50 g. of green powder (45% yield of acetohydroxamic acid). The infrared spectrum and X-ray diffraction pattern of the salt were identical with those of the authentic sample.

Reaction of the Sodium Salt of Nitroethane with Dilute Sulfuric Acid. The usual procedure[24] was employed. An 85% yield of the 2,4-DNP of acetaldehyde, m.p. 142–144°, was obtained. In addition, a 2% yield of the copper salt of acetohydroxamic acid was isolated.

Reaction of the Ethyl Nitronic Ester of 2-Nitrobutane with Dilute Sulfuric Acid. One gram of the ester in 25 ml. of cold 95% ethanol was treated with 100 ml. of the 2,4-DNP reagent.[20] A voluminous precipitate formed in *ca.* 5 sec. An additional 50 ml. of 95% ethanol was added and the mixture was heated, whereupon the solid dissolved. Hot water was then added until precipitation began and then the system was allowed to cool. In this way 1.56 g. (81% yield) of the 2,4-DNP of butanone, m.p. 100–102.5°, was obtained.

Reaction of the Sodium Salt of p-Nitrophenylnitromethane with 37% Hydrochloric Acid. One gram (4.90 mmoles) of the nitro salt was added over a 2-min. period to 20 ml. of stirred, 37% hydrochloric acid at 3 to 5°. After 9 min. of stirring at 5 to 10°, the mixture was poured into 300 ml. of ice-cold water. After 10 min. the slurry was filtered and the white solid was washed with 100 ml. of cold water; this solid (crop 1) weighed 0.665 g. and melted at 116–123° dec. It gives a strong Beilstein test and is a 68% yield of crude *p*-nitrobenzhydroxamic acid chloride. Extraction of the aqueous phase with benzene gave an additional 0.22 g., m.p. 85 to 105° dec. (crop 2).

Recrystallization of crop 1 from benzene–petroleum ether (70% recovery) raised the melting point to 125.8–126.7° (118° preheat). A second recrystallization did not raise the melting point (lit.[25] m.p. 123.5–124° and 115–117°). The infrared spectrum (Nujol mull) of the hydroxamic acid chloride has strong bands at 3.1–3.3, 6.56, 7.38, 7.48, 9.96, and 11.74 μ.

(23) W. Wise and W. W. Brandt, *J. Am. Chem. Soc.*, **77**, 1058 (1955); W. Wise, Ph.D. Thesis, Purdue University, 1955.
(24) K. Johnson and E. F. Degering, *J. Org. Chem.*, **8**, 10 (1943).

(25) H. Rheinboldt, *Ann.*, **451**, 175 (1927); A. Werner, *Ber.*, **27**, 2847 (1894).