pathway and gives large rate increases over nonassisted solvolysis. For acid-sensitive substrates it holds advantages over formic acid (or trifluoroacetic acid).

Experimental Section

Materials.—The sulfonates were prepared by standard procedures and had properties in accordance with literature values: **1**, mp 37–38° (lit.[10] mp 37.5–38.2°); **2**, mp 31–32° (lit.[11] mp 33.5–34.2°); **3**, mp 65.7–66.5° (lit.[12] mp 68.6–69.2°); **4**, mp 57.0–57.5° (lit.[13] mp 57–58°); 2-phenylethyl *p*-nitrobenzenesulfonate, mp 97–98° (lit.[14] mp 101.5–102°); ethyl *p*-nitrobenzenesulfonate, mp 90.2–91.0° (lit.[15] mp 91°).

2-(2-Furyl)ethanol was prepared by lithium aluminum hydride reduction of 2-furylacetic acid.[16] After work-up in the usual fashion, the furylethanol was characterized by nmr, and converted directly into the rather unstable tosylate (**6**), mp 29–30° (from hexane), characterized by nmr.

2,2,2-Trifluoroethanol was purchased from Halocarbon Products Corp., Hackensack, N. J., dried over molecular sieves (Union Carbide Corp. 4A),[17] and distilled prior to initial use. Shiner, *et al.*,[5] outline efficacious recovery procedures.

Kinetic Methods.—The usual sealed ampoule technique was used. Titrations were carried out with standardized 0.01 *N* potassium hydroxide in TFE, using a Metrohn Model E-336-A potentiograph with an EA 120 U electrode. The midpoint of the derivative titration curve was used as the end point. For the solutions buffered with sodium acetate, the titrant was a standardized solution of perchloric acid (0.03 *N*) in TFE. The same electrode was used with the potentiograph.

Rate constants were generally determined from 16 to 18 points, which were treated by the least-squares program LSKIN 1.[18]

Registry No.—**1,** 4455-09-8; **2,** 80-40-0; **3,** 14503-40-3; **4,** 5107-52-8; **5,** 36809-05-9; **6,** 36809-06-0; trifluoroethanol, 75-89-8.

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(10) W. H. Saunders, Jr., S. Asperger, and D. H. Edison, *J. Amer. Chem. Soc.*, **80**, 2421 (1958).

(11) S. Winstein and H. Marshall, *ibid.*, **74**, 1120 (1952).

(12) W. H. Saunders, Jr., D. G. Bushman, and A. F. Cockerill, *ibid.*, **90**, 1775 (1968).

(13) S. Winstein, C. R. Lindegren, H. Marshall, and L. L. Ingraham, *ibid.*, **75**, 147 (1953).

(14) J. Banger, A. F. Cockerill, and G. L. O. Davies, *J. Chem. Soc. B*, 498 (1971).

(15) F. Bell, *J. Chem. Soc.*, 2770 (1928).

(16) K. Yu. Novitskii, Kh. Gresel, and Yu. K. Yur'ev, *Zh. Org. Khim.*, **1**, 539 (1965).

(17) L. L. Ferstandig, private communication, reports that this is a very effective way of drying TFE.

(18) D. F. DeTar and C. E. DeTar, "Computer Programs for Chemistry," W. A. Benjamin, New York, N. Y., 1968.

The Reaction of Nitrous Acid with Oximes

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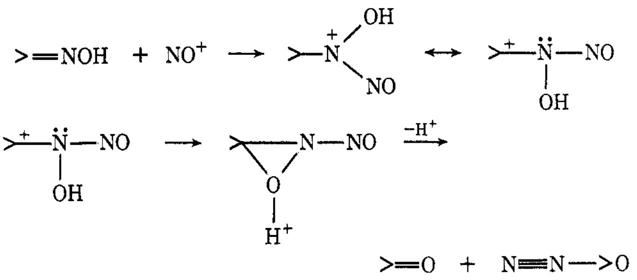
The oxidation of oximes with nitrous acid is a known procedure for the recovery of aldehydes and ketones from the parent oximes. Although this method has been widely utilized, little has appeared in the literature concerning the mechanism of the reaction. Kainz and Huber[1] have studied the reaction of nitrous acid with the oximes of cyclohexanone, benzoin, and acetone. They found that N_2O predominated as the off-gas with N_2 being formed in lesser amount. They hypothesized the intermediacy of both a nitrimine and nitramide from which N_2O could be derived. No mechanistic explanation was offered, however, for N_2 formation. Furthermore, Horner *et al.*, have reported that aldoximes react with "nitrous gases" to give azine bisoxides, and that these azine bisoxides give either N_2O and carbonyl compound or a nitrimine.[2]

More recently Wieland and Grim[3] reported that treatment of butanedione monooxime with ^{18}O-enriched nitrous acid under N_2 resulted in an 89% enrichment of nitrous oxide ($N_2{}^{18}O$), the oxygen of which came only from the nitrous acid and not from the oxime. They therefore proposed the following mechanism.



In this report, we shall deal with the ^{15}N nitrous acid catalyzed decomposition of oximes and the probable modes of formation of N_2O, N_2, and NO therefrom.

Experimental Section[4]

In a typical experiment equimolar amounts of oxime and ^{15}N sodium nitrite was dissolved in a solution containing 45 ml of H_2O and 125 ml of dioxane. Helium was passed through the reaction system and the attached gas sampling tubes. When a helium atmosphere had been obtained, an amount of 50% aqueous sulfuric acid was introduced equivalent to either the amount of sodium nitrite or to a twofold excess. Gas samples were taken at predetermined times, and the reaction mixture was analyzed for aldehyde and other organic products by standard quantitative methods.[5] The gas samples were analyzed by mass spectroscopy and compared to an assay on the ^{15}N sodium nitrite, which was decomposed by aqueous acid under helium. A quantitative estimate of the contribution by oxime and nitrous acid to the various products could then be made by comparing the amount of ^{15}N products in the assay to the ^{15}N products from the reactions.

Results

The results of our experiments are given in Table I. In the reaction of butyraldoxime, the presence of excess mineral acid has a pronounced effect on both the yield of butyraldehyde and on the distribution of gas between N_2O and NO. While the difference in yield between that reaction and the one with only nitrous acid can be attributed partially to a difference in rate of reaction, the difference in gas distribution is too great to allow for this simple explanation. It should also be noted that the nitrogen in N_2O and N_2 comes almost equally from the oxime and nitrous acid, while the nitrogen in NO comes exclusively from

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(1) G. Kainz and H. Huber, *Mikrochim. Acta*, **3**, 337 (1959).

(2) L. Horner, L. Hockenberger, and W. Kimse, *Ber.*, **94**, 290 (1961).

(3) T. Wieland and D. Grim, *ibid.*, **96**, 275 (1963).

(4) Mass spectra were obtained on a CEC21-130 mass spectrometer by Mr. B. E. Wilkes, UCC Analytical Department.

(5) S. Siggia, "Quantitative Organic Analysis," 3rd ed, Wiley, New York, N. Y., 1967; and The Union Carbide Chemicals Company Laboratory Manual, General Methods of Analysis.

TABLE I

Aldoxime	$H^+/Na^{15}NO_2/$ Oxime	% $H^{15}NO_2$ Reacted	Yield, %: Aldehyde	Yield, %: Formic acid	Yield, %: Glyoxylic acid	Yield, %: Benzoic acid	Composition of off-gases,[a] % from $H^{15}NO_2$: N_2O	Composition of off-gases,[a] % from $H^{15}NO_2$: NO	Composition of off-gases,[a] % from $H^{15}NO_2$: N_2
Butyraldoxime	2.0/1.0/1.0	97.8	100.0				76.7 (50.6)	2.4 (100.0)	20.4 (53.1)
Butyraldoxime	1.0/1.0/1.0	90.8	69.8				22.1 (53.3)	67.2 (101.9)	10.7 (53.8)
Phenylglyoxaldoxime	2.0/1.0/1.0	79.4	58.8	14.2		13.6	30.7 (53.0)	56.5 (100.0)	12.9 (56.9)
Phenylglyoxaldoxime	1.0/1.0/1.0	52.1	20.3	21.8		18.4	36.1 (56.4)	44.3 (100.0)	21.4 (55.1)
Glyoxime	4.0/2.0/1.0	100.0	33.4	17.7[b]	16.5		50.1 (48.2)	40.4 (98.2)	8.7 (53.4)
Glyoxime	2.0/2.0/1.0	93.8	12.7	30.0[b]	25.8		12.2 (53.5)	82.0 (99.2)	5.8 (50.1)

[a] Gas samples were taken at appropriate intervals and were measured by wet-test meter. The yields of gases varied between 90–100% of theoretical. [b] Based upon 2 mol of formic acid per 1 mol of glyoxime.

HNO_2. Nitrogen is produced in almost the same order of magnitude in either reaction. However, in the reaction catalyzed by strong acid, almost 77% of the gas is N_2O and 2% is NO, whereas in the mineral acid free reaction (*i.e.*, weak acid catalyzed), the roles are reversed, *i.e.*, 67% of the gas is NO and 22% is N_2O.

In the reactions of phenylglyoxaldoxime the effect of excess mineral acid is less pronounced. The distribution of gases remains approximately the same, although in the case where no excess acid was present somewhat less reaction had taken place, as evidenced by both the amount of nitrous acid that reacted and the yield of products. This reaction also distinguishes itself from that of butyraldoxime with two features: the fragmentation to give formic acid, and the majority of off-gas being nitric oxide in either strong or weak acid.

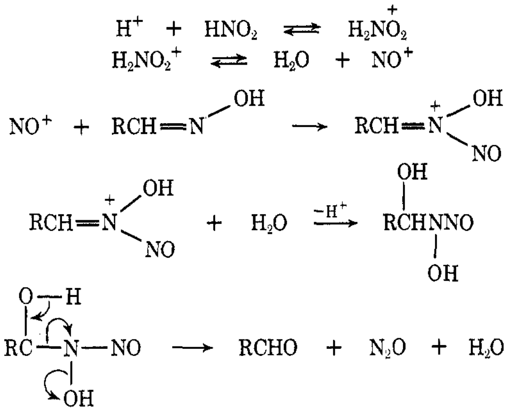
The reactions of glyoxime seem to be more like the butyraldoxime with the change in relative amounts of NO and N_2O going from strong to weak acid conditions. In the strong acid case, about equal amounts of N_2O and NO are produced. When no excess mineral acid is present, the N_2O is reduced drastically while NO production is increased twofold. The nitrogen evolution remains constant. Another striking aspect of this reaction is the low yields of glyoxal, concurrent with very high yields of the fragmentation product, formic acid. The yield of formic acid is even higher in the weak acid medium, to the detriment of glyoxal formation. In either case, the amount of glyoxime reacted (the remainder of glyoxime is either recovered unreacted or gives unobserved products) to give observed products is quite low.

Discussion

The reaction of butyraldoxime with nitrous acid in the presence of strong mineral acid follows the same general course described by Kainz and Huber[1] in that the gas mixture consists of ~76% N_2O and ~20% N_2 with a trace of NO. The high yield (100%) of butyraldehyde speaks for the completeness of the reaction.

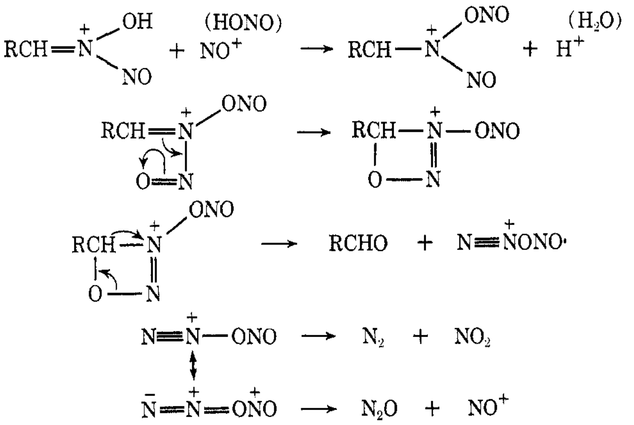
The mechanism proposed by Wieland[2] suffers from one defect. Wieland's reactions were carried out in a nitrogen atmosphere and therefore nitrogen evolution was never measured. Thus the mechanism contains no means for its formation. Furthermore, the utilization of a three-membered ring to describe what could more easily be envisioned as the addition and loss of water tends to complicate the situation.

Alternatively, we envision that the mechanism for N_2O formation is as follows.



This mechanism allows for Wieland's ^{18}O results and also necessitates that half of the nitrogen in N_2O come from oxime and nitrous acid.

For N_2 formation, we propose the following steps initially involving the nitrosated oxime.



The NO_2^+ thus formed can be eliminated by reaction with nitrous acid to give N_2O_4, a precursor of nitric and nitrous acids, both of which are acceptable oxidizing agents. The final step is an alternative step for nitrous oxide formation which allows for only the oxygen of the oxime to wind up in the nitrous oxide. This pathway, then, might explain Wieland's observation of only 89% enrichment in his studies.

The above mechanistic scheme is quite similar to those proposed by Doyle[6] for the reactions of nitrosonium ions with imines and azines.[6] Furthermore, the equal abundance of ^{15}N from nitrous acid and oxime is also explained.

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(6) M. P. Doyle, Abstracts, 161st National Meeting of the American Chemical Society Los Angeles, Calif., March 28–April 2, 1971, ORGN-15.

The reaction of butyraldoxime with nitrous acid without excess mineral acid must follow, in part, a different pathway because the major off-gas is NO (67%). As in the excess mineral acid catalyzed reaction, both the N_2 and N_2O show a 50% enrichment in ^{15}N. Thus these gases come equally from nitrous acid and oxime. The fact that so much NO is produced and that it all comes from the nitrous acid forms the basis for our considerations in this case. It should be emphasized that this NO does indeed come from a reaction of nitrous acid with the oxime. Under the same conditions of solvents, concentration, and temperature, nitrous acid does not react in a self-decomposition to give NO as an off-gas. Only when the oxime is added is NO produced.

One possibility that might explain the difference is as follows. In the presence of mineral acid a rapid reaction takes place to give the nitrosonium ion, and it is this NO^+ which is doing the reacting at an extremely

$$H^+ + HNO_2 \rightleftharpoons H_2NO_2^+$$

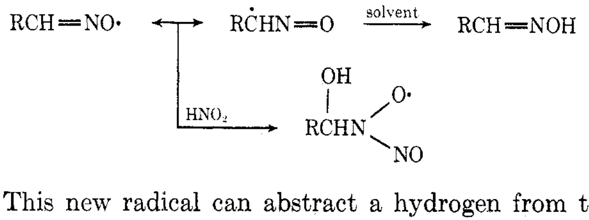
$$H_2NO_2^+ \rightleftharpoons H_2O + NO^+$$

rapid rate. On the other hand, when there is no excess mineral acid present, it is nitrous acid, HNO_2, which is reacting as an oxidizing agent.

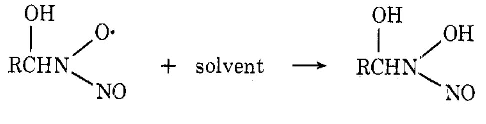
Other oxidizing agents that have been reported to react with oximes are ceric ion,[7] palladium(IV) acetate,[8] lead tetraacetate,[8] and NO_2.[8] The proposed intermediate product of these reactions is the iminoxyl radical, $RCH{=}NO\cdot$. We similarly propose that, in the absence of mineral acid, nitrous acid reacts with butyraldoxime to give the iminoxyl radical, NO, and water.[9]

$$RCH{=}NOH + HNO_2 \longrightarrow RCH{=}NO\cdot + NO + H_2O$$

In compliance with our observations, the NO thus produced will come only from the nitrous acid. The iminoxyl radical thus produced can now react in one of two ways. It can abstract a hydrogen from the solvent to give back the starting oxime, or it can react with more nitrous acid in an addition across the double bond to give another radical.



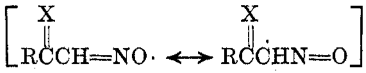
This new radical can abstract a hydrogen from the solvent to give the precursor already postulated to give the aldehyde and N_2O.



$$RCH(OH)N(O\cdot)NO + \text{solvent} \longrightarrow RCH(OH)N(OH)NO$$

The remaining N_2O and N_2 would be derived from a scheme similar to those proposed above for the reactions carried out in strong acid.

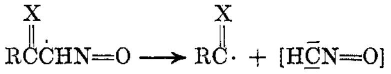
The major difference between the foregoing butyraldoxime reaction with nitrous acid and the reaction of phenylglyoxaldoxime or glyoxime seems to lie in the degree to which either the free radical (iminoxyl) or ionic (nitrosonium ion) enters reaction. In the case of the iminoxyl route, the intermediate would be



A B

$$\left[\underset{A}{R\overset{X}{\overset{\|}{C}}CH{=}NO\cdot} \longleftrightarrow \underset{B}{R\overset{X}{\overset{\|}{C}}\dot{C}HN{=}O}\right]$$

The above resonance hybrid could react with nitrous acid either as A or B. If it reacts as A, the reaction would follow the same course as previously described. On the other hand, B would be highly prone to acyl cleavage and might therefore react as follows.



1 2

$$R\overset{X}{\overset{\|}{C}}\dot{C}HN{=}O \longrightarrow \underset{1}{R\overset{X}{\overset{\|}{C}}\cdot} + \underset{2}{[H\bar{C}N{=}O]}$$

Further oxidation and hydrolysis of **1** or **2** would give the observed cleavage products, formic acid and benzoic acid. The glyoxylic acids observed are most probably derived *via* oxidation of the parent aldehydes.

Registry No.—Nitrous acid, 7782-77-6; butyraldoxime, 110-69-0; phenylglyoxaldoxime, 522-34-9; glyoxime, 557-30-2.

Acknowledgment.—We should like to thank Dr. M. P. Doyle for his help in formulating some of the mechanisms described herein.

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[7] J. W. Bird and D. G. M. Diaper *Can. J. Chem.* **47,** 145 (1969).

[8] M. M. Frojomovic and G. Just, *Can. J. Chem.,* **46,** 3719 (1968).

[9] A similar bimolecular hydrogen abstraction has been proposed for the oxidation of formic acid by nitrous acid in dilute acidic media: J. V. L. Longstaff and K. Singer, *J. Chem. Soc.,* 2604 (1954).

A Simple High Yield Synthesis of Methanol-^{18}O and Ethanol-^{18}O[1]

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In the course of studies of kinetic oxygen isotope effects, we developed a simple high yield method for the synthesis of methanol-^{18}O and ethanol-^{18}O with negligible dilution of the label from starting $H_2{}^{18}O$. To our knowledge, no method affording these alcohols in good yield and not requiring $H_2{}^{18}O$ in large excess has yet appeared in the literature.[2] These isotopically labeled alcohols are available commercially, but a recent quotation[3] shows methanol-^{18}O (80 atom %) at \$1170 per gram, and ethanol-^{18}O (80 atom %) at \$950 per 0.5 g, or 5.6 and 12.8 times the molar cost of $H_2{}^{18}O$ (80 atom %), respectively.

Methanol-^{18}O was prepared by the hydrolysis of tri-*n*-butyl orthoformate (in excess) by $H_2{}^{18}O$ in the presence of HCl, followed by lithium aluminum hydride

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[1] Supported by NIH Grant No. GM 12278 and NSF Grant No. GB 8529 to J. F. Kirsch, and by PHS Training Grant No. 5 T01 GM 31-12.

[2] For a review, see J. L. Borowitz, A. Raviv, P. Rona, D. Sadeh, D. Samuel, and F. S. Klein, *J. Label. Compounds,* **1,** 259 (1966). The yield reported for their preparation of labeled methanol amounts to 20% based on labeled water consumed. The total amount of water used was 16 times the molar yield of methanol, which had 95% of the ^{18}O excess of the water.

[3] Miles Laboratories, Inc., Research Products Division, Catalog C, Kankakee, Ill.