tion employed for XV by using a strong acid of known dissociation constant such as picric acid. The indicator ratio $C_{A\ominus}/C_{HA}$ can be determined from the relationship

$$\left[\frac{C_{A\ominus}}{C_{HA}}\right] = \frac{\epsilon - \epsilon_{HA}}{\epsilon_{A\ominus} - \epsilon}$$

where ϵ_{HA} is the extinction coefficient for the conjugate acid at high acid concentration; $\epsilon_{A\ominus}$ is the extinction coefficient for the free anion in water and ϵ is the extinction coefficient at some intermediate acidity. The results are given in Table VI, which records the pK_a's computed from ϵ-values measured at twelve *different* wave lengths for each of 4 solutions of XV of different acid strength.

PASADENA, CALIF.

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, THE UNIVERSITY OF TEXAS]

Ozonation of Carbon–Nitrogen Double Bonds. I. Nucleophilic Attack of Ozone[1]

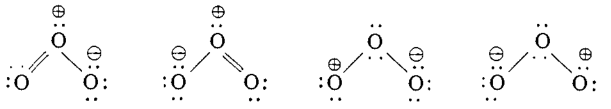
BY ALEXANDER H. RIEBEL, RONALD E. ERICKSON, CLAUDE J. ABSHIRE AND PHILIP S. BAILEY

RECEIVED MARCH 30, 1959

Contrary to reports in the literature, carbon–nitrogen double bonds, at least in Schiff bases and nitrones, are attacked by ozone. Evidence is presented that in these cases ozone behaves as a nucleophilic reagent, whereas in most other cases it acts as an electrophilic reagent. Ozonation of N-benzylidene-*t*-butylamine yielded the corresponding amide and oxazirane as non-cleavage products and benzaldehyde or benzoic acid and ammonium-type salts or other nitrogen-containing materials as cleavage products. Cleavage was the major reaction with N-benzylideneaniline and N-cyclohexylideneisobutylamine. Ozonation of N-phenylbenzaldoxime and N-*t*-butylbenzaldoxime gave initially benzaldehyde and the corresponding nitroso compounds. The latter were further oxidized by ozone to the corresponding nitro compounds.

Introduction

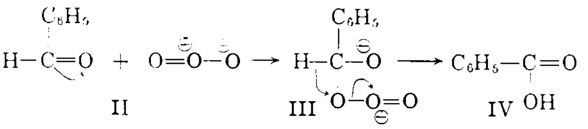
Agreement seems to have been reached that the ozone molecule has an obtuse angle (116°45′ ± 30′) and two oxygen–oxygen bonds of equal length (1.278 ± 0.002 Å.)[2-4]

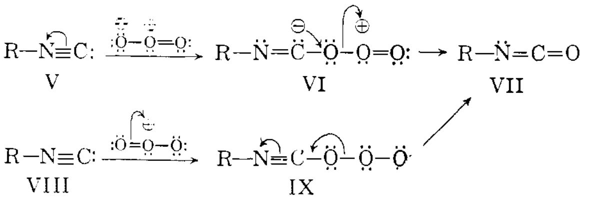


I

and can be described as a resonance hybrid of structures I. On this basis one would expect ozone to behave either as an electrophilic or as a nucleophilic reagent in its initial attack. The electrophilic attack appears to be established as the type involved in the ozonolysis of carbon–carbon unsaturated bonds[4,5] and in the reactions of ozone with amines[4,6,7] and sulfides.[4,7-9] Ozone is able to react as a radical reagent in autoxidation initiations,[4,10,11] probably because of a low lying excited state of the ozone molecule.[11] Although the possibility of ozone behaving as a nucleophilic reagent has been suggested,[4,12] no definite example has heretofore been pointed out.

The best opportunity for a nucleophilic ozone attack would appear to be with carbonyl groups or with carbon–nitrogen double or triple bonds. Briner[10,13] has shown that whereas ozone–oxygen mixtures oxidize benzaldehyde to a mixture of benzoic and perbenzoic acids, ozone–nitrogen mixtures carry the oxidation only to benzoic acid. The first reaction largely is an ozone-initiated autoxidation and undoubtedly goes by a radical mechanism.[4] The second reaction, however, must involve a nucleophilic attack of ozone followed by loss of oxygen, as shown in the changes II→III→IV.[4] Ketones are less easily attacked by ozone than are aldehydes and the reaction appears to be radical in nature.[4] The reaction between ozone and isonitriles (V) to give isocyanates has been described recently.[14] This could result from either a nucleophilic (V→VI→VII) or an electrophilic (VIII→IX→VII) attack of ozone.





It has been stated and/or assumed in the literature that carbon–nitrogen double bonds do not react with ozone, at least in pyridine,[4,15] quino-

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[1] This work was included in a paper presented at the Symposium on Ozone Chemistry, Organic Chemistry Division, 136th Meeting of the American Chemical Society, Atlantic City, N. J., September, 1959.

[2] R. Trambarulo, S. N. Ghosh, C. A. Burrus, Jr., and W. Gordy, *J. Chem. Phys.*, **21**, 851 (1953).

[3] R. H. Hughes, *ibid.*, **24**, 131 (1956).

[4] P. S. Bailey, *Chem. Revs.*, **58**, 925 (1958).

[5] P. S. Bailey, S. B. Mainthia and C. J. Abshire, to be published.

[6] A. Maggiolo and S. J. Niegowski, *Advances in Chem. Ser.*, **21**, 202 (1959).

[7] L. Horner, H. Schaefer and W. Ludwig, *Chem. Ber.*, **91**, 75 (1958).

[8] A. Maggiolo and E. A. Blair, *Advances in Chem. Ser.*, **21**, 200 (1959).

[9] D. Barnard, *J. Chem. Soc.*, 4547 (1957).

[10] E. Briner, *Advances in Chem. Ser.*, **21**, 184 (1959).

[11] C. C. Schubert and R. N. Pease, THIS JOURNAL, **78**, 2044, 5553 (1956).

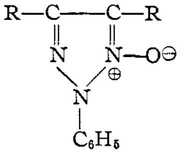
[12] J. E. Leffler, *Chem. Revs.*, **45**, 403 (1949).

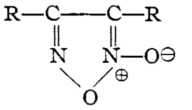
[13] E. Briner and H. Biederman, *Helv. Chim. Acta*, **15**, 1227 (1932).

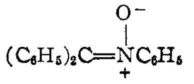
[14] H. Feuer, H. Rubinstein and A. T. Nielsen, *J. Org. Chem.*, **23** 1107 (1958).

[15] (a) J. P. Wibaut and E. C. Kooyman, *Rec. trav. chim.*, **65**, 141 (1946); (b) E. C. Kooyman and J. P. Wibaut, *ibid.*, **66**, 705 (1947); (c) F. L. J. Sixma, *ibid.*, **71**, 1124 (1952); (d) W. Shive, E. G. Ballweber and W. W. Ackermann, THIS JOURNAL, **68**, 2144 (1946).

line[4,16,17] and isoxazole systems.[18,19] In contrast to these results are the reported conversions by ozone of the imine of 2-phenylpropanal to 2-phenylpropanal,[4,20] of certain osotriazole oxides (X)[4,21] and furazan oxides (XI),[4,22] but not the parent osotriazoles or furazans, to α-diketones (or ketoaldehydes) and carboxylic acids, respectively, of certain dinitrophenylhydrazones in the steroid field to the corresponding ketones,[23a] and of a nitrone (XII) to unstated yields of benzophenone and nitrobenzene.[23b] In none of these cases, however, was it shown definitely that the cleavage was caused by ozone rather than by oxygen or what role hydrolysis played in the conversions. The present paper describes an investigation of the ozonation of carbon–nitrogen double bonds in Schiff bases and nitrones and evidence that ozone attacks these substances nucleophilically.


X


XI


$(C_6H_5)_2C{=}\overset{\overset{O^-}{|}}{N}^{+}C_6H_5$

XII

Results

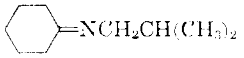
The Schiff bases ozonized were N-benzylideneaniline (XIIIb), N-benzylidene-*m*-nitroaniline (XIIIc), N-benzylidene-*t*-butylamine (XIIIa), and N-cyclohexylideneisobutylamine (XIV). All reacted with ozone, resulting in either complete or partial cleavage of the carbon–nitrogen double bond. The bases derived from benzaldehyde absorbed up to two mole-equivalents of ozone; the one derived from a ketone required only one mole-equivalent. The reactions were slow at low temperatures but occurred readily at 0°.

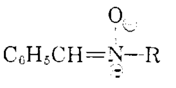
Ozonation of N-benzylidene-*t*-butylamine (XIIIa) in ethyl acetate followed by treatment of the reaction mixture with sodium hydroxide solution resulted in three major products: N-*t*-butylbenzamide (XIXa) (24% yield), 2-*t*-butyl-3-phenyloxazirane (XVIIIa)[23c] (15% yield) and benzoic acid (40% yield). When less than two mole-equivalents of ozone were employed, some benzaldehyde was isolated along with, or in place of, benzoic acid. Similar results were obtained using methylene chloride and carbon tetrachloride as solvents. When sodium hydroxide was omitted in the work-up procedure, an unstable, water-soluble powder was obtained upon evaporation of the solvent and trituration of the residue with ether. The material appeared to be either a mixture of ammonium-type salts or something convertible to such by polar solvents. The materials from ozonations in ethyl acetate and in carbon tetrachloride released benzoic acid and *t*-butylamine upon treatment with acids and bases. From the powder obtained by ozonation in methylene chloride was isolated *t*-butylammonium chloride in 28% yield and *t*-butylammonium benzoate in 5% yield.

Ozone rather than oxygen was shown to be the oxidizing agent in these reactions by the facts that (1) one or two moles of ozone was absorbed during the reactions, (2) comparable results were obtained with ozone–helium and ozone–oxygen mixtures, and (3) no reaction occurred when oxygen was passed through the ozonator and into the reaction mixture without the current being on. The latter also eliminates the possibility that benzaldehyde and *t*-butylamine were produced by hydrolysis rather than by ozonolysis during the ozonation. The possibility that hydrolysis of unreacted starting material occurred during the work-up procedure was eliminated by infrared spectral studies which showed no starting material present after the absorption of two mole-equivalents of ozone. Further, treatment of XIIIa with 20% sodium hydroxide resulted in little, if any, hydrolysis as evidenced by infrared spectra.

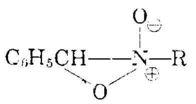
$C_6H_5{-}CH{=}N{-}R$

XIII


XIV


$C_6H_5CH{=}\overset{O^{\ominus}}{\underset{\oplus}{N}}{-}R$

XV


XVI

a, R = *t*-butyl; b, R = phenyl; c, R = *m*-nitrophenyl

Ozonation of Schiff bases in which R (structure XIII) is aromatic appeared to undergo only cleavage. However, with all of the Schiff bases studied, iodometric active oxygen determinations at the end of the ozonolysis indicated 15–25% yields of active oxygen-containing materials, thought to be the corresponding oxaziranes. Emmons[24] has shown that the oxaziranes of purely aromatic Schiff bases (*e.g.*, XIIIb) are too unstable to be isolated. Upon ozonolysis in either acetic acid or ethyl acetate, yields of 39–45% benzoic acid and traces of nitrobenzene were obtained from N-benzylideneaniline (XIIIb). The remaining material was an intractable, insoluble, unstable powder. It was the major product using methylene chloride solvent. The only successful reaction

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(16) (a) L. M. Schenck and J. R. Bailey, This Journal, **62**, 1967 (1940); (b) L. M. Schenck and J. R. Bailey, *ibid.*, **63**, 1365 (1941); (c) A. F. Lindenstruth and C. A. VanderWerf, *ibid.*, **71**, 3020 (1949).

(17) (a) J. P. Wibaut and H. Boer, *Koninkl. Ned Akad. Wetenschap Proc.*, **53**, 19 (1950); (b) H. Boer, F. L. J. Sixma and J. P. Wibaut, *Rec. trav. chim.*, **70**, 509 (1951); (c) J. P. Wibaut and H. Boer, *ibid.*, **74**, 241 (1955).

(18) (a) E. P. Kohler, This Journal, **46**, 1733 (1924); (b) E. P. Kohler and N. K. Richtmyer, *ibid.*, **50**, 3092 (1928).

(19) J. Meisenheimer, *Ber.*, **54**, 3206 (1921).

(20) W. Krabbe, A. Seher and E. Polzin, *ibid.*, **74**, 1892 (1941).

(21) M. Milone, *Gazz. chim. ital.*, **63**, 329 (1933); *C. A.*, **27**, 5075 (1933).

(22) (a) C. R. Kinney, This Journal, **51**, 1592 (1929); (b) C. R. Kinney and H. J. Harwood, *ibid.*, **49**, 514 (1927).

(23) (a) G. A. Fleisher and E. C. Kendall, *J. Org. Chem.*, **16**, 556 (1951); (b) H. Staudinger and K. Miescher, *Helv. Chim. Acta*, **2**, 554 (1919).

(23c) Added in Proof.—Since the acceptance of this paper J. S. Belew and J. T. Person, *Chemistry and Industry*, 1246 (1959), have reported an unspecified yield of an oxazerane by ozonation of N-isobutylidene-*t*-butylamine.

(24) W. D. Emmons, This Journal, **79**, 5739 (1957).

with it was zinc dust distillation which gave a low yield of aniline. Upon ozonolysis of either N-benzylideneaniline (XIIIb) or N-benzylidene-*m*-nitroaniline (XIIIc) in methanol at −78° two moles of ozone was absorbed. Reduction in the cold with sodium iodide led to 28–55% yields of benzaldehyde. Decomposition occurred if the reaction mixture was not first reduced, resulting in lower benzaldehyde yields (20–24%).

The keto Schiff base, N-cyclohexylideneisobutylamine (XIV) likewise gave largely cleavage. The formation of a primary amide is impossible in this case. A small amount of material with properties of an oxazirane also was obtained. The yield of cyclohexanone was never greater than 50%. Perhaps this was partially due to the fact that the oxazirane formed from XIV is unstable and decomposes to give condensation products of cyclohexanone and isobutyraldehyde imine.[24]

The nitrones studied were N-phenylbenzaldoxime (XVb) and N-*t*-butylbenzaldoxime (XVa). Two moles of ozone per mole of nitrone were absorbed to give benzaldehyde (XX) and nitrobenzene (XXIVb) or 2-methyl-2-nitropropane (XXIVa). The absorption was rapid and complete even at −78°. Throughout the ozonation the presence of a blue to green color indicated that nitroso compounds XXIII were precursors to the nitro compounds XXIV. This was proved in the case of XVb, not only by the isolation of 25–40% yields of nitrosobenzene (XXIIIb) after the absorption of one mole-equivalent of ozone, but also by stopping the ozonolysis at successive stages and plotting the concentrations of nitrosobenzene, nitrobenzene and benzaldehyde, as determined by infrared spectra, against the amount of ozone consumed. Figure 1 shows that nitrosobenzene (XXIIIb) is produced initially and is further oxidized to nitrobenzene (XXIVb), the concentration of which does not exceed that of nitrosobenzene until after one mole-equivalent of ozone has been absorbed. Until near the end, when some benzaldehyde is autoxidized to benzoic acid, the concentration of benzaldehyde approximates the sum of the concentrations of nitrosobenzene and nitrobenzene.

The results of ozonation of XVb with ozone–helium rather than ozone–oxygen mixtures showed that ozone rather than oxygen was the principal oxidant in these reactions.

The ozonation of nitrosobenzene (XXIIIb) also was studied. One mole-equivalent of ozone was absorbed; infrared spectra indicated that the product was pure nitrobenzene (XXIVb), an 88% yield of which was isolated.

Discussion

There are four principal ways in which ozone could attack a carbon–nitrogen double bond: (1) an addition to the double bond as with carbon–carbon double bonds to give a four- or a five-membered ring,[5] (2) an electrophilic attack on the nitrogen atom of the double bond followed by loss of oxygen, (3) an electrophilic attack on the entire double bond followed by loss of oxygen, and (4) a nucleophilic attack on the carbon atom of the double bond followed by loss of oxygen.[24a]

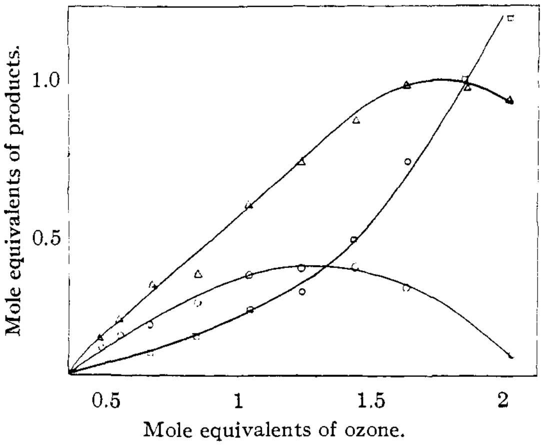

Fig. 1.—Ozonization of N-phenylbenzaldoxime; mole equivalents of products *vs.* mole equivalents of ozone: Δ, benzaldehyde; O, nitrosobenzene; □, nitrobenzene.

Since both the Schiff bases XIII and the nitrones XV utilized only one atom of the ozone molecule in the formation of the first detectible products, it appears that route 1 can be eliminated and that the reactions involved ozone attack followed by loss of an oxygen molecule. The fact that the nitrones reacted with ozone considerably more readily than did the Schiff bases is consistent with a nucleophilic ozone attack (path 4) but not with an electrophilic ozone attack (paths 2 or 3). Further, route 2 with the Schiff bases XIII should lead to nitrone formation (XV), analogous to the formation of amine oxides from tertiary amines.[4,6,7] The nitrones XV were shown to be stable to the work-up conditions used in the ozonation of the Schiff bases and thus, if formed, they should have been isolable, or else the final products of the ozonolysis of the Schiff bases XIII should have been the same as those starting with the nitrones. Actually, not even the blue to green color of the nitroso compounds XXIII was detected during ozonation of the Schiff bases XIII.

Path 3, of course, could explain the production of oxaziranes (XVIII) from Schiff bases (XIII) and, conceivably, the formation of benzaldehyde (XX) and the nitroso compounds (XXIII) from the nitrones (XV); Emmons[25] has suggested that the reaction of oxaziranes with peracids to give nitroso compounds involves an unstable intermediate of type XVI. The formation of XVI by ozone attack on XV seems unlikely, however, for the reason already given and because the high polarity of XV should favor an unsymmetrical rather than a symmetrical attack. Neither can path 3 be the principal course of the reaction with Schiff bases, since it was shown that the oxazirane formed from

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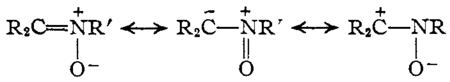
[24a] A fifth possibility which has been suggested is an electrophilic attack of ozone on the carbon atom of the carbon–nitrogen double bond, followed by loss of oxygen. Such an attack is logical only in regard to the ozonation of nitrones which are resonance hybrids of the structures:



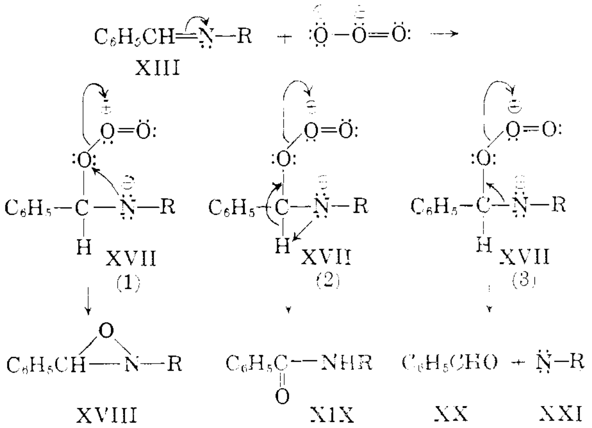
$$R_2C{=}\underset{\displaystyle O^-}{\underset{|}{\overset{+}{N}}}R' \longleftrightarrow R_2\overset{-}{C}{-}\underset{\displaystyle O}{\underset{\|}{\overset{+}{N}}}R' \longleftrightarrow R_2\overset{+}{C}{-}\underset{\displaystyle O^-}{\underset{|}{N}}R'$$

Thus, the greater ease of ozonation of nitrones than of Schiff bases is best explained by the nucleophilic ozone attack (path 4).

[25] W. D. Emmons, THIS JOURNAL, **79**, 6522 (1957).

N-benzylidene-*t*-butylamine (XIIIa) is stable under the reaction conditions employed. It was not changed appreciably upon exposure to ozone, heat or concentrated sodium hydroxide. Thus, the other products obtained from ozonation of XIIIa had to originate through some other route.

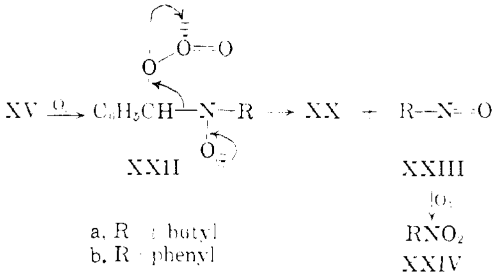
The most reasonable explanation for the results described for the Schiff base ozonations is a nucleophilic attack of ozone on the carbon atom of the carbon–nitrogen double bond to give something resembling XVII, which can undergo any one of the reactions shown: (1) loss of oxygen and ring closure to the oxazirane (XVIII), (2) loss of oxygen and shift of a proton to give an amide (XIX) and (3) loss of oxygen and cleavage of the carbon–nitrogen double bond to give benzaldehyde (XX) and fragment XXI. The nucleophilic ozone attack appears to be the only explanation for amide formation. Another route from XVII to XIX, however, is a Baeyer–Villiger hydride ion shift to give the enol of XIX, followed by ketonization. In the cleavage case (route 3) the benzaldehyde is converted to benzoic acid, by an ozone-initiated autoxidation and/or by a nucleophilic ozone attack followed by loss of oxygen.[4,10] The active oxygen content of the reaction mixtures, though due largely to the presence of oxaziranes, was partially caused by perbenzoic acid and benzoyl peroxide, products to be expected from autoxidation of benzaldehyde.[4,10,26] Benzoyl peroxide was isolated in very low yield.



a, R = *t*-butyl; b, R = phenyl; c, R = *m*-nitrophenyl

Clues to the fate of fragment XXIa came from the fact that ammonium-type salts were isolated from the water-soluble powder obtained when sodium hydroxide was not used in the work-up procedure. Since it was shown that these could not have arisen by hydrolysis of the Schiff base, they must have been produced by abstraction of atoms from the medium, during the ozonation or work-up procedure, by XXIa or some polymer thereof. This is especially apparent in the case of the *t*-butylammonium chloride which was obtained from ozonations of XIIIa in methylene chloride. Less is known about the fate of XXIb since the powder obtained during work-up of the ozonation of XIIIb was water insoluble and so unstable that it decomposed during all efforts to identify it.

The nitrone XV results also are most easily explained by the nucleophilic ozone attack as shown in XXII to give benzaldehyde (XX) and nitroso compounds XXIII. Further ozone attack on XXIII could occur by either an electrophilic or a nucleophilic mechanism to give nitro compounds XXIV.



Experimental[27]

The ozonator, ozonation flasks and general ozonation procedure were described in earlier publications.[28,29] The ozonations with ozone–helium or ozone–nitrogen mixtures were carried out by passing the usual ozone–oxygen mixture over silica gel at −78° until the desired amount of ozone was absorbed.[30] Oxygen in the system was swept out by a helium or nitrogen stream. The ozone desorption was brought about by raising slowly the temperature of the silica gel while the helium or nitrogen stream was being passed through the gel and into the reaction mixture. The solvents used in the ozonations were pure and anhydrous. The infrared spectra were taken with a Baird Associates, Inc. infrared recording spectrophotometer using matched cells of 0.054 and 0.064 mm. Gas chromatograms were obtained with a Perkin–Elmer vapor fractometer, model 154-B.

Starting Materials.—**N-Benzylideneaniline (XIIIb)** (m.p. 51–52°),[31] **N-benzylidene-*m*-nitroaniline (XIIIc)** (m.p. 72–73°)[32] and **N-benzylidene-*t*-butylamine (XIIIa)** (b.p. 95–100° (15 mm.))[24,33] were prepared by earlier reported methods. **N-Cyclohexylideneisobutylamine (XIV)** (b.p. 95–100° (20 mm.))[34] was prepared in 79% yield by refluxing a solution of 1 mole of cyclohexanone, 2 moles of isobutylamine and 250 ml. of benzene for 3 days under conditions such that the water produced during the condensation was separated. (*Anal.* Calcd. for $C_{10}H_{19}N$: C, 78.4; H, 12.5; N, 9.1. Found: C, 77.0; H, 12.2; N, 8.8.[35]). **N-Phenylbenzaldoxime (XVb)** (m.p. 110–111°) was prepared in 85–90% yields from benzaldehyde and nitrobenzene,[36] and **N-*t*-butylbenzaldoxime (XVa)** (m.p. 75–76°) was obtained from the corresponding oxazirane XVIIIa in quantitative yield.[24] Nitrosobenzene (XXIIIb) (m.p. 66–67°) was prepared by the usual method.[37] 2-Methyl-2-nitrosopropane (XXIIIa) (m.p. 82–84°) was prepared by the method of Emmons,[25] and 2-methyl-2-nitropropane (XXIVa) (b.p. 125–126°) was kindly furnished by Commercial Solvents, Inc.

Ozonation of N-Benzylidene-*t*-butylamine (XIIIa) in Ethyl Acetate. **(a) Without Sodium Hydroxide Treatment.**

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[26] C. S. Marvel and V. Nichols, *J. Org. Chem.*, **6**, 296 (1941).

[27] Microanalyses were performed by the microanalytical laboratory of the University of Texas Biochemical Institute and by the Huffman Microanalytical Laboratories of Wheatridge, Colo.

[28] P. S. Bailey, This Journal, **78**, 3811 (1956).

[29] P. S. Bailey and S. S. Bath, *ibid.*, **79**, 3120 (1957).

[30] G. A. Cook, A. D. Kiffer, C. V. Klumpp, A. H. Malik and L. A. Spence, *Advances in Chem. Ser.*, **21**, 44 (1959).

[31] L. A. Bigelow and H. Eatough in H. Gilman and A. H. Blatt, "Organic Sytheses," Coll. Vol. I, 2nd edition, John Wiley and Sons, Inc., New York, N. Y., 1941, p. 80.

[32] B. M. Bogoslavskii and N. Vatulya, *J. Gen. Chem.* (*U.S.S.R.*), **15**, 653 (1945); *C.A.*, **40**, 5708 (1946).

[33] M. D. Hurwitz, U. S. Patent 2,582,128 (Jan. 8, 1952); *C.A.*, **46**, 8146 (1952).

[34] W. D. Emmons, private communication.

[35] It is very difficult to keep this substance absolutely pure.

[36] J. Wiemann and C. Glacet, *Bull. soc. chim. France*, 176 (1950).

[37] G. H. Coleman and C. M. McCloskey, "Organic Syntheses," Coll. Vol. III, John Wiley and Sons, Inc., New York, N. Y., 1955, p. 668.

Into a solution of 5 g. of XIIIa in 130 ml. of anhydrous ethyl acetate cooled to 0°, was passed an ozone–oxygen stream containing 75 mg. of ozone per liter until 1.5 mole-equivalents of ozone had been absorbed. In other experiments up to 2 mole equivalents was absorbed. The reaction mixture was evaporated under reduced pressure at room temperature. Under addition of anhydrous ether, 0.6 g. of a fine, almost colorless, water-soluble, slightly peroxidic powder solidified. A water solution of the material gave benzoic acid (m.p. 122–123°) upon acidification with hydrochloric acid, and *t*-butylamine upon treatment with sodium hydroxide solution. The latter was identified by conversion to phenyl-*t*-butylthiourea (m.p. 123–124°) upon treatment with phenyl isothiocyanate.[38] The material decomposed rapidly to a tar on standing. Evaporation of the ether solution (from filtration of the powder) and crystallization of the residue from cold petroleum ether gave 1 g. (18% yield) of N-*t*-butylbenzamide (XIXa) melting at 134–135°.[24] Distillation of the filtrate gave 0.5 g. of benzaldehyde boiling at 75–78° (16 mm.) (semicarbazone m.p. 213°),[39] 0.2 g. of starting material (b.p. 48–50° (1 mm.)) and 0.5 g. of 2-*t*-butyl-3-phenyloxazirane (XVIIIa) (b.p. 68–72° (1 mm.)), identified by quantitative conversion to N-*t*-butylbenzamide (XIXa) (m.p. 134–135°)[24]; the remainder was a tar. Identifications of crystalline substances were by mixture melting points with authentic samples.

(b) **Sodium Hydroxide Treatment.**—In a similar reaction, 2 mole-equivalents of ozone was absorbed, the reaction mixture was evaporated under reduced pressure to one-half its volume, 100 ml. of ether was added and the resulting solution was extracted with 20% sodium hydroxide solution, washed, dried and evaporated. From the residue was obtained in the manner described above 1.3 g. (24% yield) of N-*t*-butylbenzamide (XIXa) melting at 134–135°, and 0.8 g. (15% yield) of 2-*t*-butyl-3-phenyloxazirane (XVIIIa) (b.p. 65–70° (1 mm.)). Acidification of the sodium hydroxide extract gave 1.5 g. (40% yield) of benzoic acid melting at 121–122°. The oxazirane was quantitatively converted to N-*t* butylbenzamide[24] (XIXa) (m.p. 134–135°).

When the same reaction was carried out using an ozone–helium rather than an ozone–oxygen stream the yields of N-*t*-butylbenzamide (XIXa), 2-*t*-butyl-3-phenyloxazirane (XVIIIa) and benzoic acid were 23, 12 and 21%, respectively. A 10% yield of benzaldehyde also was isolated (semicarbazone, m.p. 213°).[39] All identifications were by mixture melting points with authentic samples.

Ozonation of N-Benzylidene-*t*-butylamine (XIIIa) in Methylene Chloride.—Two mole-equivalents of ozone was passed into a solution of 5 g. of XIIIa in 100 ml. of methylene chloride as described in the ethyl acetate experiments. Evaporation of the solvent and addition of ether to the residue produced 1.6 g. of a powdery solid (precipitate A). Evaporation of the filtrate and crystallization of the residue from petroleum ether gave 1.4 g. (26% yield) of N-*t*-butylbenzamide (XIXa) which melted at 134–135° after recrystallization from a methanol–water mixture (identification by the mixture melting point method).[24] The petroleum ether filtrate slowly deposited 0.3 g. (5% yield) of *t*-butylammonium benzoate which sublimed at about 120° and was identified by comparison with an authentic sample, by displacement of benzoic acid (m.p. 121–122°) upon treatment of a water solution with hydrochloric acid, and by distillation of *t*-butylamine from an alkaline solution. Evaporation of the filtrate and distillation of the residue gave 0.5 g. (9% yield) of 2-*t*-butyl-3-phenyloxazirane (XVIIIa) (b.p. 70–72° (1.5 mm.)); identified by quantitative conversion to N-*t*-butylbenzamide,[24] (m.p. 134–135°). Precipitate A crystallized from a methanol–ether mixture to give 0.95 g. (28% yield) of *t*-butylammonium chloride which was identified by comparison with an authentic sample, by a qualitative chloride ion test, by distillation of *t*-butylamine from an alkaline solution, and by analysis.

Anal. Calcd. for $C_4H_{12}NCl$: C, 43.8; H, 11.0. Found: C, 44.3; H, 10.8.

When the reaction was repeated using an ozone–helium mixture, the yields of *t*-butylammonium chloride, N-*t*-butylbenzamide (XIXa), and 2-*t*-butyl-3-phenyloxazirane (XVIIIa) were 24, 20 and 8%, respectively. In a third run, using an ozone–oxygen mixture, the reaction mixture was poured into a sodium iodide solution as soon as the ozonation was complete. Titration of the released iodine with standard thiosulfate solution showed a 20% yield of active oxygen-containing materials which was assumed to be largely oxazirane. When a solution of the Schiff base XIIIa in methylene chloride was treated with pure oxygen under exactly the same conditions as described for the ozonolysis, no reaction occurred. Infrared spectra taken before and after oxygen passage were identical and an 82% recovery of pure starting material was made by evaporation of the solvent and distillation of the residue (b.p. 96–101° (16 mm.)). Ozonolyses using 1, 1.5 and 2 mole-equivalents of ozone were carried out and infrared spectra of the reaction mixtures taken. A comparison of the intensities of characteristic starting material bands at 908 and 962 cm.$^{-1}$ in these and in a spectrum of a comparable solution of starting material showed approximately 40, 9 and 0% of starting material in the 1, 1.5 and 2 mole-equivalents runs, respectively.

Ozonation of N-Benzylidene-*t*-butylamine (XIIIa) in Carbon Tetrachloride.—The ozonation was carried out with 1.5 mole-equivalents of ozone and a solution of 5 g. of XIIIa in 130 ml. of carbon tetrachloride as described in the ethyl acetate experiments. Evaporation of the solvent and addition of ether produced 1.0 g. of a water-soluble, slightly peroxidic powder which gave no chloride ion test and decomposed rapidly to a tar. Distillation of a basic solution of the powder gave *t*-butylamine which was converted to phenyl-*t*-butylthiourea by treatment with phenyl isothiocyanate[38] (m.p. 123–124°, no depression in a mixture melting point with an authentic sample). Partial evaporation of the mother liquor gave 0.3 g. of a more stable, water-soluble, crystalline material which gave a positive chloride ion test, released benzoic acid (m.p. 121–122°) upon treatment with hydrochloric acid and released *t*-butylamine upon treatment with sodium hydroxide (identified as phenyl-*t*-butylthiourea,[38] m.p. 123–124°). The filtrate was evaporated and the residue was crystallized by addition of petroleum ether, yielding 0.7 g. (14% yield) of N-*t*-butylbenzamide (XIXa) (m.p. 133–134°, no depression in a mixture melting point with an authentic sample). The petroleum ether filtrate slowly deposited 0.3 g. of *t*-butylammonium benzoate which was identified by comparison with an authentic sample and by conversion to *t*-butylamine and benzoic acid through methods already described. Evaporation of the filtrate and distillation of the residue gave a 10% recovery of starting material (b.p. 48–50° (1 mm.)) and a 10% yield of 2-*t*-butyl-3-phenyloxazirane (XVIIIa) (b.p. 68–70° (1 mm.), converted quantitatively to N-*t*-butylbenzamide, m.p. 133–134°, by the ferrous ion method).[24]

When the reaction was repeated (2 mole-equivalents of ozone) and was worked up by the sodium hydroxide treatment described in the ethyl acetate experiments, there was obtained N-*t*-butylbenzamide (XIXa) (21% yield, m.p. 133–134°), 2-*t*-butyl-3-phenyloxazirane (XVIIIa) (9% yield, b.p. 68–71° (1 mm.)) and benzoic acid (32% yield, m.p. 120–121°). There was isolated from the distillation residue, upon trituration with methanol at −78°, 50 mg. of dibenzoyl peroxide (m.p. 107–108°). All crystalline substances were identified by mixture melting points with authentic samples. In another instance a 19% yield of a peroxidic material was found in the reaction mixture by reduction with sodium iodide and titration of the released iodine with standard thiosulfate. It was thought to be largely the oxazirane.

Ozonation of 2-*t*-butyl-3-phenyloxazirane (XVIIIa) (3.8 g.) in methylene chloride (75 ml.) at 0° proceeded very slowly. One mole equivalent of ozone was passed through the reaction mixture and 95% of it was recovered in the potassium iodide trap. An infrared spectrum of the reaction mixture showed essentially pure oxazirane (XVIIIa) with only a very weak carbonyl peak at 1700 cm.$^{-1}$ (benzaldehyde).

Treatment of a methylene chloride solution of 2-*t*-butyl-3-phenyloxazirane (XVIIIa) with 20% sodium hydroxide solution brought about no change in XVIIIa as shown by infrared spectra. Nothing was obtained from the sodium hydroxide layer upon acidification.

Treatment of a methylene chloride solution of N-*t*-butylbenzaldoxime (XVa) with 20% sodium hydroxide solution followed by separation and evaporation of the methylene

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[38] M. Ettlinger and J. E. Hodgkins, THIS JOURNAL, **77**, 1834 (1955).

[39] A. I. Vogel, "Practical Organic Chemistry," 3rd Edition, Longmans Green and Co., London, 1956, pp. 346, 723.

chloride layer allowed a quantitative recovery of XVa (m.p. 75–76°).

Treatment of a methylene chloride solution of N-benzylidene-*t*-butylamine (XIIIa) with 20% sodium hydroxide solution brought about no change in XIIIa as shown by infrared spectra. No trace of benzaldehyde was indicated by the spectrum. The intensity of the XIIIa spectrum (960 cm.$^{-1}$ band measured) decreased by about 20%, but this probably was due to losses during the extraction, separation and drying steps.

Ozonation of N-Cyclohexylideneisobutylamine (XIV) in Ethyl Acetate.—A solution of 10 g. of XIV in 100 ml. of anhydrous ethyl acetate was ozonized by the procedure described in the preceding experiments. One mole-equivalent of ozone was absorbed. The solvent was evaporated under reduced pressure leaving 11.5 g. of an oil which upon distillation under reduced pressure gave 3 g. (48% yield) of crude cyclohexanone and 0.5 g. of a peroxidic material thought to be 2-isobutyl-3,3-pentamethyleneoxazirane (b.p. 55–60° (1.5 mm.)). The residue was a thick resin. The cyclohexanone was identified as its semicarbazone (m.p. 165–166°)[39] which was obtained in 38% yield (from XIV). In another instance the oil was converted to cyclohexanone 2,4-dinitrophenylhydrazone (m.p. 160–161°)[39] in 49% yield. A work-up procedure involving partial evaporation of the ethyl acetate, addition of water and continuous extraction with methylene chloride also gave a 49% yield of cyclohexanone isolated as the 2,4-dinitrophenylhydrazone (m.p. 160–161°).[39]

In one run an aliquot of the reaction mixture was poured into sodium iodide solution and the released iodine was titrated with standard thiosulfate. A 23% yield of active oxygen-containing material, which was assumed to be largely the oxazirane, was indicated. The remainder of the reaction mixture was diluted with ether and extracted with 20% hydrochloric acid. Evaporation of the aqueous layer and addition of methanol to the residue gave 0.2 g. of an amine salt assumed to be isobutylammonium chloride because of a qualitative chloride ion test and the release of an amine upon addition of base. From the ether layer was obtained a 20% yield of cyclohexanone isolated as the semicarbazone (m.p. 165–166°).[39] Identifications of crystalline materials were by the mixture melting point method.

Ozonation of N-Benzylideneaniline (XIIIb). (a) In Acetic Acid.—A solution of 5 g. of XIIIb in 60 ml. of glacial acetic acid was ozonized at 17° just as described in preceding experiments. Two mole-equivalents of ozone was absorbed. The solvent was evaporated under reduced pressure and the residue was treated with 200 ml. of anhydrous ether, giving 1.7 g. of a powdery solid (precipitate A). The ether layer was extracted with 20% NaOH, dried and evaporated. Distillation of the residue gave 0.33 g. of a mixture of nitrobenzene and benzaldehyde (b.p. 68° (12 mm.)).[40] Acidification of the sodium hydroxide layer with 50% sulfuric acid gave 1.3 g. (39% yield) of benzoic acid (m.p. 121–122°). Precipitate A was insoluble in water and soluble in acetic acid, mineral acids, methanol and pyridine. It decomposed slightly above 100°. A mixture of 1 g. of the material with 10 g. of zinc dust gave 0.1 g. of aniline upon distillation (identified as benzenesulfanilide, m.p. 108°). The material perhaps is an oxygenated polymer of XXIb; it may also be combined with benzoic acid.

Anal. Found: C, 67.2; H, 5.4; N, 8.1.

In another instance the reaction mixture was reduced immediately with sodium iodide and the released iodine was titrated with standard thiosulfate solution. A 16% yield of active oxygen-containing material was indicated.

(b) In Ethyl Acetate.—The ozonation was carried out at 0° with 5 g. of XIIIb in 100 ml. of anhydrous ethyl acetate. Two mole-equivalents of ozone was absorbed. The solvent was evaporated under reduced pressure and 150 ml. of ether was added to the residue. The resulting mixture was extracted with 20% sodium hydroxide solution and dried. Evaporation of the ether layer and distillation of residue gave 0.35 g. of a mixture of nitrobenzene and benzaldehyde (b.p. 73–75° (16 mm.)).[40] Acidification of the sodium hydroxide layer gave 1.5 g. (45% yield) of benzoic acid (m.p. 121–122°).

(c) In Methylene Chloride.—The ozonation was carried out at 0° with 5 g. of XIIIb in 50 ml. of anhydrous methylene chloride. Infrared spectra of aliquots taken after the absorption of 1 and 2 mole-equivalents of ozone showed the presence of considerable amounts of benzaldehyde and small amounts of nitrobenzene[40]; no starting material was indicated in the 2 mole spectrum. When the reaction mixture (after absorption of 2 mole-equivalents of ozone) was cooled to −78°, 5 g. of a crystalline material precipitated. It was similar to the precipitates obtained from ozonolyses in other solvents, but was more unstable.

(d) In Methanol.—A solution of 5.4 g. of XIIIb in 100 ml. of anhydrous methanol was ozonized at −76°. Two mole-equivalents of ozone was absorbed. The cold reaction mixture was poured into a cold mixture of sodium iodide and methanol. The released iodine was reduced with sodium bisulfite. The methanol was evaporated under reduced pressure and the remaining aqueous solution was extracted with ether. Evaporation of the ether layer left a tar. The sodium bisulfite layer was acidified with hydrochloric acid and extracted with ether. The ether layer was extracted with sodium carbonate solution. Evaporation of the ether layer and treatment of the residue with phenylhydrazine gave a 54% yield of benzaldehyde phenylhydrazone which melted at 155–156°[39] after one recrystallization from methanol. Acidification of the sodium bicarbonate extract gave no benzoic acid.

In another instance the reaction mixture was not reduced with sodium iodide but was allowed to come to room temperature. At about −40° decomposition occurred leaving the reaction mixture very dark. The reaction mixture was treated with sodium bisulfite and worked up as before. The yield of benzaldehyde phenylhydrazone (m.p. 155–156°)[39] was 24%. Similar results were obtained using an ozone–nitrogen mixture instead of ozone–oxygen. Identifications were by the mixture melting point method.

Ozonation of N-Benzylidene-*m*-nitroaniline (XIIIc) in Methanol.—The reaction was carried out exactly as described for N-benzylideneaniline in the preceding experiment. Reduction with sodium iodide was carried out on the cold reaction mixture. By the work-up procedure of the preceding experiment a 40% yield of benzaldehyde phenylhydrazone was obtained (m.p. 154–156°, no depression in a mixture melting point with an authentic sample).[39]

Ozonolysis of N-Phenylbenzaldoxime (XVb). (a) Two Mole-equivalents of Ozone.—A solution of 5 g. of XVb in 75 ml. of methylene chloride was ozonized at −78°. Ozone was quantitatively absorbed until 2 mole-equivalents had reacted. During the ozonolysis the characteristic green color of nitrosobenzene developed but disappeared toward the end of the reaction (similar results were noted with other runs at temperatures ranging from 0 to −78°). The solution was evaporated under vacuum and the residue was treated with a solution of 4 g. of semicarbazide hydrochloride, 40 g. of sodium acetate and 50 ml. of water. Fifty milliliters of Skellysolve B was added and the mixture was shaken, kept cold for several hours and filtered; 3.75 g. (90% yield) of benzaldehyde semicarbazone melting at 219–221°.[39] The organic layer was collected, dried and distilled, giving 2.1 g. (66% yield) of nitrobenzene (XXIVb) boiling at 95° (15 mm.). From some runs low yields of benzoic acid (partial autoxidation of benzaldehyde) were obtained.

The reaction was repeated using an ozone–nitrogen mixture (6.2 g. of XVb in 70 ml. of methylene chloride). The green nitrosobenzene color was evident throughout the reaction. The reaction mixture was evaporated and the residue was separated by distillation into two fractions: (1) 3.6 g., b.p. 96° (30 mm.); (2) 1.5 g., b.p. 110–112° (30 mm.). Infrared spectra calculations showed fraction 1 to be 49% benzaldehyde and 51% nitrobenzene and showed fraction 2 to be 100% nitrobenzene; molar yields, 51% benzaldehyde (XX) and 84% nitrobenzene (XXIVb).

(b) One Mole-equivalent of Ozone.—The reaction was carried out as in the preceding experiments, using the ordinary ozone–oxygen mixture on a solution of 5.2 g. of XVb in 100 ml. of methylene chloride, but stopping the reaction after 1 mole of ozone had been absorbed. The solvent was removed by distillation and the residue was distilled at 5 mm. pressure; the volatile nitrosobenzene (XXIIIb) was collected over a wide boiling range (0.8 g., 30% yield, white crystals melting to green liquid at 68°); the yield of benzaldehyde (XX) was 1.2 g. (43%) boiling at 52° (5 mm.).

The reaction was repeated with an ozone–helium mixture. The solvent was evaporated and petroleum ether was added,

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[40] Identified by I. R. bands at 1520 and 1340 cm.$^{-1}$ (nitrobenzene) and 1704 and 830 cm.$^{-1}$ (benzaldehyde).

resulting in the formation of two layers. Several triturations of the brown layer with petroleum ether caused it to solidify; identified as starting material (XVb), 27% recovery, m.p. 110°. The green layer obviously contained nitrosobenzene, but it was not isolated; treatment with semicarbazide by the usual method gave a 52% yield of benzaldehyde semicarbazone (m.p. 219–221°).[39]

(c) **Infrared Spectral Technique.**—The spectra of benzaldehyde (XX), nitrosobenzene (XXIIIb), nitrobenzene (XXIVb), benzoic acid and starting material (XVb) were determined at a number of known concentrations and Beer's law plots for the various bands were obtained. The bands employed are shown in Table I. Six grams of the nitrone (XVb) in 34 ml. of methylene chloride was ozonized at 0° until 2 mole-equivalents of ozone had been absorbed. During the course of the ozonolysis ten 1-ml. aliquots were withdrawn, their infrared spectra determined, and the concentrations of benzaldehyde, nitrosobenzene and nitrobenzene in each determined by means of the aforementioned Beer's law plots. In most cases two or more bands were used to check calculations. The results are shown in Fig. 1. For comparison with the preceding experimental methods it is noteworthy that the concentrations of benzaldehyde (XX), nitrosobenzene (XXIIIb), nitrobenzene (XXIVb) and benzoic acid were calculated as 65, 35, 27 and 0%, respectively, after the absorption of one mole-equivalent of ozone, and as 68, 0, 82 and 15%, respectively, after the absorption of two mole-equivalents of ozone. In these calculations corrections were made for solvent evaporation during the ozonolysis. Such corrections were not made in Fig. 1, however.

TABLE I

INFRARED SPECTRUM BANDS USED IN FOLLOWING THE COURSE OF OZONOLYSES BY SPECTRAL METHODS

Compound	Band frequencies, cm.$^{-1}$
Benzaldehyde	1700, 1310, 825, 1200, 635
Nitrosobenzene	1110 (corr. for weak nitro peak)
Nitrobenzene	855, 790, 1338
Benzoic acid	810
N-*t*-Butylbenzaldoxime	1120, 810
2-Methyl-2-nitropropane	1340, 860

Similar calculations made on the spectra of an ozone-helium ozonolysis reaction mixture, in which 2 moles of ozone had reacted, showed a 94% yield of benzaldehyde and a 98% yield of nitrobenzene.[40]

(d) **Gas–Liquid Partition Chromatography Results.**—The concentrations of benzaldehyde, nitrosobenzene and nitrobenzene as determined by calculations from gas–liquid partition chromatography curves were 49, 20 and 45% after the absorption of one mole-equivalent of ozone, and were 100, 0 and 100% after the absorption of 2 mole-equivalents of ozone. The columns used were of di-2-ethylhexyl sebacate and diisodecyl phthalate and the temperature was 163°.

Ozonation of Nitrosobenzene (XXIIIb).—Into a solution of 5.1 g. of nitrosobenzene (XXIIIb) in 50 ml. of methylene chloride cooled to 0° was passed an ozone–oxygen mixture until the potassium iodide trap showed the reaction to be complete. One mole-equivalent of ozone was absorbed. An infrared spectrum of the solution showed that only nitrobenzene was present. Distillation *in vacuo* gave 5.14 g. (87% yield) of nitrobenzene (XXIVb) boiling at 92° (16 mm.).

Ozonolysis of N-*t*-Butylbenzaldoxime (XVa). (a) **Two Mole-equivalents of Ozone.**—Two mole-equivalents of ozone was quantitatively absorbed when an ozone–oxygen stream was passed through a solution of 5 g. of XVa in 40 ml. of methylene chloride at −78°, after which iodine was released in the potassium iodide trap. Distillation gave 2.4 g. (81% yield) of 2-methyl-2-nitropropane (XXIVa) (b.p. 120–125°)[41] and 1.6 g. (54% yield) of benzaldehyde (b.p. 175–179°). The residue was extracted with base and the base extract was acidified, yielding 0.8 g. (21% yield) of benzoic acid (m.p. 119–120°). Identifications were by comparison of infrared spectra with those of authentic samples. In another experiment, after removal of the solvent and distillation of XXIVa, benzaldehyde was isolated as the phenylhydrazone; 4.7 g. (85% yield), m.p. 156–157°.[39]

(b) **Infrared spectral study** was carried out in the same manner as with XVb. The green color of 2-methyl-2-nitrosopropane[25] (XXIIIa) was noticed throughout the ozonolysis until the very end. However, it was so rapidly oxidized to the nitropropane that it was impossible to determine the percentage present by infrared spectra. A plot of concentrations of the two products *versus* mole-equivalents of ozone absorbed showed benzaldehyde (XX) and 2-methyl-2-nitropropane (XXIVa) to be present in approximately equal concentrations until toward the end of the reaction when some autoxidation of benzaldehyde occurred. The corrected yields were 42% benzaldehyde (XX), 38% nitropropane (XXIVa) and 46% starting material (XVa) after one mole-equivalent of ozone, 90% benzaldehyde after 1.8 mole-equivalents of ozone and 46% benzaldehyde, 41% benzoic acid and 89% nitropropane (XXIVa) after 2 mole-equivalents of ozone.

(c) **Gas–Liquid Partition Chromatography Results.**—The course of the ozonolysis was also followed with aliquot samples taken and chromatographed during the ozonolysis. The chromatograms were compared with the chromatograms of standard samples of benzaldehyde, 2-methyl-2-nitrosopropane (XXIIIa)[25] and 2-methyl-2-nitropropane (XXIVa). The temperatures used were 50, 128 and 163° and the columns were the same as in the case of XVb. The results were comparable to those obtained from infrared studies. For example, the corrected yields of benzaldehyde (XX), nitrosopropane (XXIIIa) and nitropropane (XXIVa) were 54, *ca.* 1 and 52%, respectively, after 1 mole-equivalent of ozone, and 70, 0 and 88% after 2 mole-equivalents of ozone.

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(41) H. B. Hass, E. B. Hodge and B. M. Vanderbilt, *Ind. Eng. Chem.*, **28**, 339 (1936), reports the boiling point as 126°.