1-(*n*-Butyl-*n*-butyrylamino)-2-butanone (XXII) was isolated from the ozonation reaction mixture of 1-dibutylamino-2-butanone (XV) by preparative vpc. Its infrared spectrum (liquid film) showed carbonyl peaks at 1730 (ketone) and 1642 cm^{-1} (amide). Its nmr spectrum (neat liquid) included peaks at τ 5.98 (singlet, two protons, $O{=}C{-}CH_2N{<}$), 6.70 (triplet, two protons, $>NCH_2Pr$), 7.66 (complex, four protons, $EtCH_2{-}C{=}O$ and $CH_3CH_2C{=}O$), and 8.55 (complex, six protons, $O{=}CCH_2CH_2CH_3$ and $-CH_2CH_2CH_2CH_3$) ppm. Peaks appeared in the mass spectrum at *m/e* 214 (mol wt + 1), 213 (mol wt), 184 (mol wt − Et), 156 (mol wt − EtCO or Bu), and 142 (mol wt − PrCO).

Anal. Calcd for $C_{12}H_{23}NO_2$: N, 6.57. Found: N, 6.24.

Ozonation of Tri-*n*-butylamine (IV).—A solution of 4 g (21.6 mmol) of tributylamine (IV) in 50 ml of the solvent was treated with 1 mol equiv of ozone from an ozone–nitrogen mixture at −45°. The ozone absorption was quantitative. The reaction mixture was allowed to warm to room temperature and was analyzed for aldehydes by vpc. If the solvent was pentane, the reaction mixture was then extracted with three 15-ml portions of water. When the solvent was methanol, chloroform, methylene chloride, or carbon tetrachloride, the solvent was first removed under reduced pressure and 50 ml of pentane was added before the water extraction. Otherwise the separation of amine oxide from other products was incomplete. The water extract was diluted to 50 ml. The aqueous solution (5 ml) was used for the amine oxide determination by the titanium chloride method.[10] In those cases where the original solvent was a chlorinated hydrocarbon, 5 ml of the aqueous solution was used for the amine hydrochloride (ammonium salt) determination, by titration with 0.1 *N* silver nitrate solution after addition of 0.5 ml of saturated sodium bicarbonate solution and some potassium chromate indicator. The remaining water extract was made basic with sodium hydroxide and continuously extracted with ether for 24 hr. Analysis of the ether extract by vpc showed largely dibutylamine. The basic extract was acidified with hydrochloric acid and continuously extracted with ether for 24 hr. The ether extract was analyzed for carboxylic acids by vpc. The pentane layer was analyzed by vpc for the other volatile products and unreacted tributylamine.

Ozonation of 1-di-*n*-butylamino-2-butanone (XV) was carried out in the same manner as described for tributylamine.

Registry No.—IV, 102-82-9; XV, 16656-38-5; XXII, 16656-39-6; XXIV, 16656-40-9.

Acknowledgment.—The authors are grateful for grants from the National Science Foundation and the Robert A. Welch Foundation which made this work possible.

Ozonation of Amines. III. *t*-Butylamine[1]

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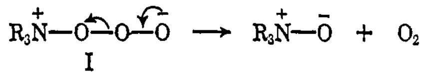
Received January 31, 1968

Ozonation of *t*-butylamine in chlorinated solvents gave as major products *t*-butylammonium chloride, 2-methyl-2-nitropropane, and *t*-butyl isocyanate. In isooctane, the nitroalkane and azoxyisobutane were produced, along with 2,4,4-trimethyl-2-pentanol. All amine ozonations were carried out under conditions whereby neither ozone nor the amine alone reacted appreciably with the solvent. The results are explained in terms of an initial electrophilic ozone attack on the amine to give an adduct which can either lose molecular oxygen or dissociate to nitrogen cation radicals and the ozonate anion radical.

In the preceding paper[1] of this series, evidence was presented to show that the competition observed between amine oxide formation and side-chain oxidation during ozonation of certain tertiary amines involves two competing fates of an initial amine–ozone adduct (I), as illustrated in eq 1 and 2a or b. In the first paper of the series[2] a third fate of adduct I was proposed, namely, dissociation into nitrogen cation radicals and the ozonate anion radical (eq 3), followed by further reactions of these species. The formation of Wurster's salts by ozonation of phenylene diamines[3] and of ammonium ozonate by ozonation of liquid ammonia[4] are apparent examples of this reaction course open to I.

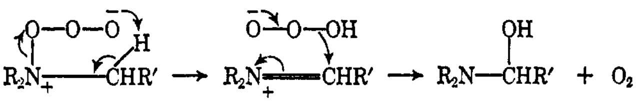
To gain further information concerning the possibility of the fate of I exemplified by eq 3, the ozonation of *t*-butylamine in several different solvents was studied. In this case there is little possibility of the occurrence of routes 2, since they would have to involve a β position. The principal competition, therefore, should be between the reactions described by eq 1 and 3.

Since our first report on this work, at the International Oxidation Symposium in 1967,[2] Bachman and Strawn[5] have reported the oxidation of several different primary amines to the corresponding nitro compounds by means of ozone. The present paper describes a more thorough study of a primary amine in which all products are described and reasonable reaction paths thereto suggested. Together, these two works constitute the first detailed study of the ozonation of primary amines.[6]

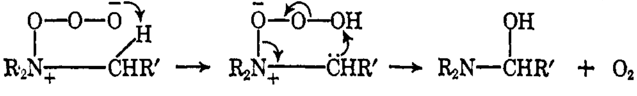


$$\mathrm{R_3\overset{+}{N}{-}O{-}O{-}\overset{-}{O}} \longrightarrow \mathrm{R_3\overset{+}{N}{-}\overset{-}{O}} + \mathrm{O_2} \tag{1}$$

I



(2a)



(2b)

$$\underset{\mathrm{I}}{\mathrm{R_3\overset{+}{N}{-}O{-}O{-}\overset{-}{O}}} \rightleftharpoons \mathrm{R_3\overset{+}{N}\cdot} + \cdot\ddot{O}{-}\ddot{O}{-}\overset{-}{\ddot{O}}: \tag{3}$$

Experimental Section

Equipment and Procedures.—The ozonation setup and procedures, using ozone–oxygen or ozone–nitrogen, and the method of determining molecular oxygen yields are described in earlier

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[1] For paper II of this series, see P. S. Bailey, D. A. Mitchard, and A. Y. Khashab, *J. Org. Chem.*, **33**, 2675 (1968).

[2] P. S. Bailey, J. E. Keller, D. A. Mitchard, and H. M. White, Advances in Chemistry Series, American Chemical Society, Washington, D. C., in press; paper presented at the International Oxidation Symposium, San Francisco, Calif., Aug 1967.

[3] R. W. Layer, *Rubber Chem. Technol.*, **39**, 1584 (1966).

[4] I. J. Solomon, K. Hattori, A. J. Kacmarek, G. M. Platz, and M. J. Klein, *J. Amer. Chem. Soc.*, **84**, 34 (1962).

[5] G. B. Bachman and K. G. Strawn, *J. Org. Chem.*, **33**, 313 (1968).

[6] For a historical background, see ref 1 and 5 and P. S. Bailey, *Chem. Rev.*, **58**, 925 (1958).

TABLE I

OZONATION OF *t*-BUTYLAMINE IN VARIOUS SOLVENTS

Expt	Amine,[a] mmol	O_3,[b] mmol		Solvent (ml)	Temp, °C	O_2 evolved, mmol	$t\text{-BuNO}_2$		$t\text{-BuN=C=O}$		$t\text{-Bu}\overset{+}{N}H_3Cl^-$		Total yield, %
		Passed	Reacted				mmol	Yield, %	mmol	Yield, %	mmol	Yield, %	
1	5	6.1	3.9	$CHCl_3$ (50)	−60	3.5	0.9	18	0.8	16	3.2	64	98
2	5	6.0	4.2	$CHCl_3$ (25)	−65	...	0.9	18	0.9	18	3.0	60	100[c]
3	5	6.0	4.9	CH_2Cl_2 (50)	−78	4.5	1.5	30	0.5[d]	10	2.9	58	98
4	20	30	27.9	CH_2Cl_2 (50)	−70	...	5.9	30	1.5	8	10.9	55	93
5	20	40	40	CCl_4 (50)	−20	...	8.9	45	2.5[d]	13	6.2	31	89
6	20	45	43.4	CCl_4 (50)	−20	...	8.5	43	2.0[d]	10	5.5	28	81
7	10	30	23.6	CH_3Cl (25)	−70	...	3.6	36	0.2	2	2.1	21	59
8	2.5	6.2	6.2	Isobutane (10)	−78	...	1.1	44[e]	...	...	...	...	44
9	3	9.6	8.1	Isooctane (25)	−78	...	1.8	60[f]	...	...	...	...	104[f]

[a] Preliminary studies indicated that all of the amine reacted under the conditions used and yields of products were calculated on this basis. [b] In all experiments except 9, ozone–nitrogen streams were employed. The amount reacted is amount passed minus that appearing in KI trap. [c] In addition 2% acetone, 1% *t*-butyl alcohol, and 1% isobutane were produced. [d] From one-third to one-half of this material was actually N,N′-di-*t*-butylurea, but the yield was calculated on basis of isocyanate. [e] *t*-Butyl alcohol (0.7 mmole) also was a product. [f] Other products were 2,4,4-trimethyl-2-pentanol (0.34 mmol) and azoxyisobutane (XV, 0.66 mmol or 44%). The determination of XV was crude, explaining the higher than 100% total yield.

publications.[7] Vpc determinations in most cases were carried out on a F & M Model 500 gas chromatograph using a 0.25 in. × 20 ft column of 20% Carbowax 20M on Chromosorb P. In one case (expt 2, Table I) an Aerograph 1520B chromatograph with an 0.125 in. × 20 ft 20% Carbowax 20M column was employed. A column temperature of 75° was used for *t*-butyl isocyanate (XI), acetone (shoulder on isocyanate peak), *t*-butyl alcohol, nitrosoisobutane (IV), and isobutane, whereas 125° was used for nitroisobutane (V) and azoxyisobutane (XV). Yields were determined on the F & M chromatograph by comparison with standard solutions of known compounds. With the Aerograph 1520B, an internal standard of benzene was used at 75° and a standard of *p*-xylene was used at 125°. For preparative chromatography an Aerograph 90-P3 chromatograph and a 0.375 in. × 20 ft 30% Carbowax 20M column were employed. Nmr spectra were obtained with a Varian Associates A-60 spectrometer, using a tetramethylsilane internal standard.

Materials.—Distillation Products No. 6772 *t*-butylamine was dried over potassium hydroxide pellets and distilled from fresh pellets: bp 46°. *t*-Butylhydroxylamine (III),[8a] nitrosoisobutane (IV),[8b] nitroisobutane (V),[8c] *t*-butylisocyanate (XI),[9] N,N′-di-*t*-butylurea (XII),[10] and 2,4,4-trimethyl-2-pentanol[11] were prepared by known literature procedures. Solvents were pure and anhydrous.

Ozonation of *t*-Butylamine (VI).—In a typical experiment a solution of 0.365 g (5.00 mmol) of *t*-butylamine in 50 ml of chloroform was cooled to −60° and treated with an ozone–nitrogen stream containing 6 mmol of ozone; the exit gases were analyzed for molecular oxygen.[7] From the beginning of the ozonation, a slight blue color, due to nitrosoisobutane (IV), appeared but was replaced at the end of the ozonation by the purple color of unreacted ozone. A precipitate of *t*-butylammonium chloride (VIIIa and b) formed during the ozonation. The excess ozone was purged with nitrogen and the colorless solution above the precipitate was analyzed by vpc for all products except the *t*-butylammonium chloride and N,N′-di-*t*-butylurea (XII). The reaction mixture was then evaporated to dryness and the *t*-butylammonium chloride was determined by dissolving it in water and titrating for chloride ion. In those cases where the urea (XII) was a product, it was left behind when the *t*-butylammonium chloride was dissolved in water and was identified by infrared spectral comparison with a known sample. Ozonations in the other solvents were similar except that there was no salt precipitate formed in isooctane or isobutane. The results are shown in Table I.

When the pure solvents, except chloroform, were treated with ozone at the temperatures used in the amine ozonations, 99–100% of the ozone employed passed into the KI trap. A vpc determination of 25 ml of isooctane treated with 10 mmol of ozone at −78° showed nothing but isooctane. In the case of chloroform, 0.9 mmol of 5.9 mmol of ozone passed into 50 ml of solvent underwent reaction. However, in another experiment, 10 mmol of ozone was passed through 50 ml of chloroform at −60°, and the exit gases were passed into 10% sodium carbonate solution. The chloroform was then washed with the carbonate solution, which was then acidified with nitric acid and treated with silver nitrate. Only a faint turbidity was produced. Treatment of 50 ml of chloroform with 20 mmol of *t*-butylamine at either room temperature or −65° for 3 hr produced only 5 mg of *t*-butylammonium chloride. Similar treatment of carbon tetrachloride gave 6 mg of the salt at −20° and 16 mg of salt at room temperature. Collins[12] reports only a 2% yield of triethylammonium chloride from treatment of carbon tetrachloride with triethylamine at room temperature for 72 hr.

Ozonation of 25 ml of neat *t*-butylamine was carried out at −50° with 60 mmol of ozone. The reaction mixture was treated with excess hydrochloric acid, and the resulting solution was extracted with ether. The products, qualitatively identified by vpc, were nitrosoisobutane (IV), nitroisobutane (V), and azoxyisobutane (XV). The azoxyisobutane was isolated by preparative vpc: bp 148°; $n^{26}\text{D}$ 1.4171;[13] nmr showed two peaks of equal intensity at τ 8.58 and 8.76 ppm. This was used as a standard in later vpc determinations.

Anal. Calcd for $C_8H_{18}N_2O$: C, 60.72; H, 11.47; N, 17.70; mol wt, 158. Found: C, 60.44; H, 11.21; N, 17.78; mol wt, 153.

Ozonations of *t*-butylhydroxylamine (III) and nitrosoisobutane (IV) were carried out and products were determined as described for *t*-butylamine. These results are shown in Table II.

Results and Discussion

The results of ozonation of *t*-butylamine (VI) in several different solvents are shown in Table I. The major products in the chlorinated solvents were *t*-butylammonium chloride (VIIIa and b), 2-methyl-2-nitropropane (V), and either *t*-butyl isocyanate (XI) or, sometimes, N,N′-di-*t*-butylurea (XII).

As stated in the first paper of this series,[2] the only initial reaction likely to occur between ozone (an electrophile) and an amine (a nucleophile) is formation of an adduct (I). The route from there to the nitroiso-

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[7] (a) P. S. Bailey, *J. Amer. Chem. Soc.*, **78**, 3811 (1956); (b) P. S. Bailey, *J. Org. Chem.*, **22**, 1548 (1957); (c) P. S. Bailey and A. M. Reader, *Chem. Ind.* (London), 1063 (1961); (d) P. S. Bailey, P. Kolsaker, B. Sinha, J. B. Ashton, F. Dobinson, and J. E. Batterbee, *J. Org. Chem.*, **29**, 1400 (1964); (e) A. M. Reader, P. S. Bailey, and H. M. White, *ibid.*, **30**, 784 (1965).

[8] (a) W. D. Emmons, *J. Amer. Chem. Soc.*, **79**, 5739 (1957); (b) W. D. Emmons, *ibid.*, **79**, 6522 (1957); (c) N. Kornblum, R. J. Clutter, and W. J. Jones, *ibid.*, **78**, 4003 (1956).

[9] B. Brauner, *Chem. Ber.*, **12**, 1874 (1879).

[10] N. Bortnick, L. S. Luskin, M. D. Hurwitz, and A. W. Rytina, *J. Amer. Chem. Soc.*, **78**, 4358 (1956).

[11] J. J. Ritter, *ibid.*, **70**, 4253 (1948).

[12] R. F. Collins, *Chem. Ind.* (London), 704 (1957).

[13] J. P. Freeman [*J. Org. Chem.*, **28**, 2508 (1963)] reports bp 50° (20 mm) and $n^{20}\text{D}$ 1.4208.

Table II

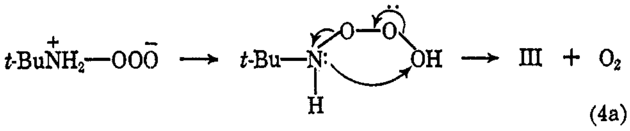
Ozonation of *t*-Butylhydroxylamine (III) and Nitrosoisobutane (IV)

Compd ozonized	Compd, mmol	O_3,[a] mmol— Passed	Reacted	Solvent (ml)	Temp, °C	O_2 evolved, mmol	—*t*-$BuNO_2$— mmol	Yield, %	Other products	Total yield, %	O_3[b]/ S.M.	O_2[c]/ *t*-$BuNO_2$
III	2.5	6.0	3.8	CH_2Cl_2 (50)	−50	2.6	1.2	48	$t\text{-Bu}\overset{+}{\mathrm{N}}\mathrm{H_2OH}$ Cl^- 35%	83	1.5	2.2
III	2.3	5.0	3.8	CCl_4 (50)	−18	3.9	1.7	74		74	1.7	2.3
III	2.5	6.0	4.4	Isooctane[d] (100)	−60	4.4	2.3	92		92	1.8	1.9
IV	2.0	3.0	1.4	Isooctane (50)	−78	1.4	1.8	90	Some unreacted IV	90	0.7	0.8

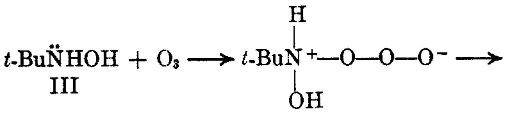
[a] From an ozone–nitrogen stream. [b] Millimoles of ozone to millimoles of starting material (S.M.) reacting. [c] Millimoles of oxygen evolved to millimoles of nitroisobutane obtained. [d] More than the usual amount of solvent was necessary because of solubility difficulties.

butane (V) in all solvents should logically involve the reaction course described by eq 1. Since, however, the amine oxide produced in this case (II) is primary, it is not stable and most likely rearranges to a hydroxylamine (III). A similar set of reactions should convert III into the nitrosoisobutane (IV) and IV into the nitroisobutane (V). These reactions, described by eq 1 and 4–6 are summed up in eq 7. An alternative to the reactions of eq 1 and 4 is shown by eq 4a. Results from separate ozonations of *t*-hydroxylamine (III) and nitrosoisobutane (IV), shown in Table II, are in agreement with this reaction scheme, as are the facts that the blue color of the nitroso compound (IV) was observed throughout most of each ozonation and that IV was identified by vpc as a product of the ozonation of neat *t*-butylamine.

$$\underset{\text{II}}{t\text{-Bu}\overset{+}{\mathrm{N}}\mathrm{H_2{-}O^-}} \longrightarrow \underset{\text{III}}{t\text{-BuNHOH}} \qquad (4)$$

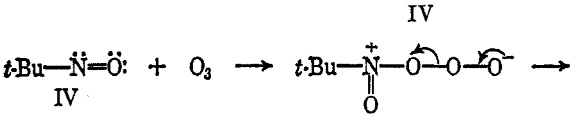


(4a)



$$\underset{\text{III}}{t\text{-Bu}\ddot{\mathrm{N}}\mathrm{HOH}} + O_3 \longrightarrow t\text{-Bu}\overset{\displaystyle \mathrm{H}}{\underset{\displaystyle \mathrm{OH}}{\mathrm{N}^+}}\mathrm{{-}O{-}O{-}O^-} \longrightarrow$$

$$O_2 + t\text{-Bu}\ddot{\mathrm{N}}\mathrm{(OH)_2} \longrightarrow \underset{\text{IV}}{t\text{-Bu{-}}\ddot{\mathrm{N}}\mathrm{{=}}\ddot{\mathrm{O}}\mathrm{:}} + \mathrm{HOH} \qquad (5)$$

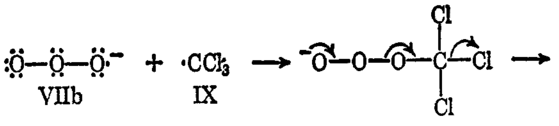


$$O_2 + \underset{\text{V}}{t\text{-BuNO}_2} \qquad (6)$$

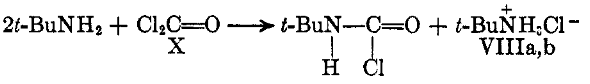
$$\underset{\text{VI}}{t\text{-BuNH}_2} + 3O_3 \longrightarrow \underset{\text{V}}{t\text{-BuNO}_2} + 3O_2 + H_2O \qquad (7)$$

It was shown in separate experiments that at the ozonation reaction temperatures no appreciable amount of hydrogen chloride was produced by passage of ozone through the solvents in the absence of the amine, nor was any appreciable amount of ammonium salt (VIIIa and b) produced by reaction of the amine with the solvent in the absence of ozone, even at room temperature. Thus, the logical route to *t*-butylammonium chloride (VIIIa and b) is *via* nitrogen cation radical (VIIa) and the ozonate anion radical (VIIb) produced in minute equilibrium amounts through dissociation of the amine–ozone adduct (eq 3). In the case of chloroform solvent, the proposed reaction course is shown by eq 3 and 8–11 and is summed up in eq 12. Nitrogen cation radical VIIa stabilizes itself by abstraction of hydrogen from a solvent molecule to give ammonium cation VIIIa and solvent radical IX, (eq 8). The ozonate anion radical (VIIIb) and the solvent radical (IX) then interact to give chloride anion (VIIIb) and phosgene (X, eq 9). Phosgene and *t*-butylamine interact to produce *t*-butyl isocyanate (XI) and additional salt *via* reactions 10 and 11. This reaction was verified in a separate experiment at the ozonation temperature. Only at room temperature is the isocyanate (XI) converted into N,N-di-*t*-butylurea (XII, eq 14) by excess *t*-butylamine. Equation 13 is a summation of 7 and 12, assuming the two fates of the amine–ozone adduct (I) to occur equally. The fact that the results of expt 1 and 2 of Table I agree well with the stoichiometry of eq 13 increases confidence in the validity of the mechanism. The production of ammonium salts by ozonation of amines in chloroform has been reported previously,[14,15] but it was not shown that such did not arise either by action of the amine on the solvent or through oxidation of the solvent by ozone.

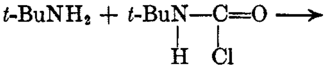
$$\underset{\text{VIIa}}{t\text{-Bu}\dot{\mathrm{N}}\mathrm{H_2}^+} + CHCl_3 \longrightarrow \underset{\text{VIIIa}}{t\text{-Bu}\overset{+}{\mathrm{N}}\mathrm{H_3}} + \underset{\text{IX}}{\cdot CCl_3} \qquad (8)$$



$$\underset{\text{VIIIb}}{Cl^-} + \underset{\text{X}}{Cl_2C{=}O} + O_2 \qquad (9)$$



$$2t\text{-BuNH}_2 + \underset{\text{X}}{Cl_2C{=}O} \longrightarrow t\text{-Bu}\underset{\displaystyle \mathrm{H}}{\mathrm{N}}\mathrm{{-}}\underset{\displaystyle \mathrm{Cl}}{\mathrm{C}}\mathrm{{=}O} + \underset{\text{VIIIa,b}}{t\text{-Bu}\overset{+}{\mathrm{N}}\mathrm{H_3Cl^-}} \qquad (10)$$



$$t\text{-BuNH}_2 + t\text{-Bu}\underset{\displaystyle \mathrm{H}}{\mathrm{N}}\mathrm{{-}}\underset{\displaystyle \mathrm{Cl}}{\mathrm{C}}\mathrm{{=}O} \longrightarrow$$

$$\underset{\text{XI}}{t\text{-BuN{=}C{=}O}} + \underset{\text{VIIIa,b}}{t\text{-Bu}\overset{+}{\mathrm{N}}\mathrm{H_3Cl^-}} \qquad (11)$$

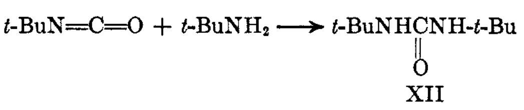
$$4t\text{-BuNH}_2 + O_3 + CHCl_3 \longrightarrow$$

$$t\text{-BuN{=}C{=}O} + 3t\text{-Bu}\overset{+}{\mathrm{N}}\mathrm{H_3Cl^-} + O_2 \qquad (12)$$

$$5t\text{-BuNH}_2 + 4O_3 + CHCl_3 \longrightarrow$$

$$t\text{-BuNO}_2 + t\text{-BuN{=}C{=}O} +$$

$$3t\text{-BuNH}_3{}^+Cl^- + 4O_2 + H_2O \qquad (13)$$



$$t\text{-BuN{=}C{=}O} + t\text{-BuNH}_2 \longrightarrow \underset{\text{XII}}{t\text{-BuNH}\underset{\displaystyle \overset{\|}{\mathrm{O}}}{\mathrm{C}}\mathrm{NH}\text{-}t\text{-Bu}} \qquad (14)$$

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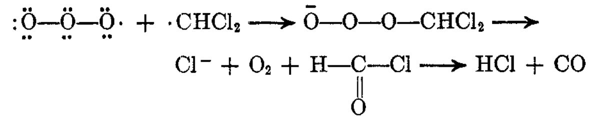
[14] W. Strecker and M. Baltes, *Chem. Ber.*, **54**, 2693 (1921).

[15] G. P. Shulman, *Can. J. Chem.*, **43**, 3069 (1965).

The results from the other chlorinated solvents are more difficult to interpret, especially in regard to the production of the isocyanate (XI) or the urea (XII) in the methylene chloride and methyl chloride reactions. However, if it is assumed that the major reactions occurring are analogous to those suggested for chloroform, reasonable correlations with experimental results can be obtained. For methylene chloride, the over-all reaction analogous to reaction 12 is represented by eq 17, which is a summation of eq 3, the analog of 8 (to give $\cdot CHCl_2$), 15, and 16.

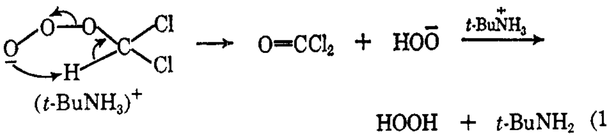


$$:\ddot{\underset{\cdot\cdot}{O}}-\ddot{\underset{\cdot\cdot}{O}}-\ddot{\underset{\cdot\cdot}{O}}\cdot + \cdot CHCl_2 \longrightarrow \bar{O}-O-O-CHCl_2 \longrightarrow Cl^- + O_2 + H-\underset{\underset{O}{\|}}{C}-Cl \longrightarrow HCl + CO \quad (15)$$

$$t\text{-}BuNH_2 + HCl \longrightarrow t\text{-}Bu\overset{+}{N}H_3Cl^- \quad (16)$$

$$2t\text{-}BuNH_2 + O_3 + CH_2Cl_2 \longrightarrow 2t\text{-}Bu\overset{+}{N}H_3Cl^- + O_2 + CO \quad (17)$$

A likely explanation for the formation of *t*-butyl isocyanate (XI) in the methylene chloride reaction is *via* eq 18 followed by 10 and 11.[16] A summation of these with eq 17 and two times eq 7 gives eq 19, which fits the data of expt 3 and 4 of Table I reasonably well.



(18)

$$7t\text{-}BuNH_2 + 8O_3 + 2CH_2Cl_2 \longrightarrow 2t\text{-}BuNO_2 + 4t\text{-}Bu\overset{+}{N}H_3Cl^- + t\text{-}BuN{=}C{=}O + 7O_2 + CO + H_2O_2 + 2H_2O \quad (19)$$

For the ozonation in methyl chloride the reaction analogous to those represented by eq 12 and 17 is described by eq 20. Although the results in methyl chloride are far from quantitative, reaction 7 appears to be twice as important as reaction 20. Such a summation gives eq 21, which at least fits the amine–ozone stoichiometry of expt 7, Table I. The isocyanate obtained in the methyl chloride experiment must have come from chloroform, methylene chloride, or carbon tetrachloride impurities.

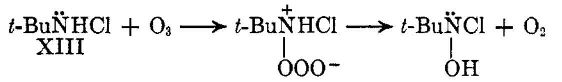
$$t\text{-}BuNH_2 + O_3 + CH_3Cl \longrightarrow t\text{-}BuNH_3{}^+Cl^- + O_2 + H_2C{=}O \quad (20)$$

$$3t\text{-}BuNH_2 + 7O_3 + CH_3Cl \longrightarrow 2t\text{-}BuNO_2 + t\text{-}Bu\overset{+}{N}H_3Cl^- + 7O_2 + 2H_2O + H_2C{=}O \quad (21)$$

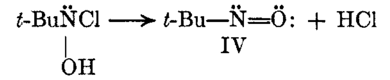
The reactions in carbon tetrachloride leading to the ammonium salt are, of necessity, somewhat different from those in the other chlorinated solvents, since the nitrogen cation radical (VIIa) from eq 3 must find some source of hydrogen other than the solvent, presumably another amine molecule as shown in eq 22. There are, of course, several possible routes from this point on to products. The one most attractive to us is similar to the mechanistic course suggested by Lautenberger, *et al.*,[17] for the photochemical reaction of amines with carbon tetrachloride. It is described by eq 23, 9, 24, 25, 16, 10, 11, and 6. One difference in our scheme and that of Lautenberger, *et al.*, is that species XIII cannot react in the same way as proposed by the other authors since the alkyl group in XIII is tertiary. We suggest that it is attacked by ozone to give nitrosoisobutane (IV) as is shown in eq 24 and 25. A summation of the above equations with eq 3 provides eq 26. If this occurs to the extent of 20% and eq 7 to 80%, the result is eq 27, which fits fairly well the data of expt 5, in which 89% of the starting amine was accounted for. There obviously are other competing reactions leading to these and other products which prevent better agreement between our results and eq 27.

$$\underset{\text{VIIa}}{t\text{-}Bu\underset{\cdot}{\overset{+}{N}}H_2} + t\text{-}Bu\ddot{N}H_2 \longrightarrow \underset{\text{VIIIa}}{t\text{-}Bu\overset{+}{N}H_3} + t\text{-}Bu\underset{\cdot\cdot}{\dot{N}}H \quad (22)$$

$$t\text{-}Bu\underset{\cdot\cdot}{\dot{N}}H + CCl_4 \longrightarrow \underset{\text{XIII}}{t\text{-}Bu\ddot{N}HCl} + \underset{\text{IX}}{\cdot CCl_3} \quad (23)$$



$$\underset{\text{XIII}}{t\text{-}Bu\ddot{N}HCl} + O_3 \longrightarrow t\text{-}Bu\underset{\underset{OOO^-}{|}}{\overset{+}{N}}HCl \longrightarrow t\text{-}Bu\underset{\underset{OH}{|}}{\ddot{N}}Cl + O_2 \quad (24)$$



$$t\text{-}Bu\underset{\underset{OH}{|}}{\ddot{N}}Cl \longrightarrow \underset{\text{IV}}{t\text{-}Bu-\ddot{N}{=}\ddot{O}:} + HCl \quad (25)$$

$$6t\text{-}BuNH_2 + 3O_3 + CCl_4 \longrightarrow t\text{-}BuNO_2 + 4t\text{-}Bu\overset{+}{N}H_3Cl^- + t\text{-}BuN{=}C{=}O + 3O_2 \quad (26)$$

$$10t\text{-}BuNH_2 + 15O_3 + CCl_4 \longrightarrow 5t\text{-}BuNO_2 + 4t\text{-}Bu\overset{+}{N}H_3Cl^- + t\text{-}BuN{=}C{=}O + 15O_2 + 4H_2O \quad (27)$$

In addition to the major products already discussed, small amounts of di-*t*-butyl nitroxide (XIV),[18] acetone, *t*-butyl alcohol, and isobutane also were obtained from ozonation of *t*-butylamine in the chlorinated solvents. Details of the production of these substances and results of ozonation of XIV will be given in a later paper.

$$\underset{\text{XIV}}{(t\text{-}Bu)_2\dot{N}-\underset{\cdot\cdot}{\ddot{O}}: \longleftrightarrow (t\text{-}Bu)_2\ddot{N}-\underset{\cdot\cdot}{\ddot{O}}\cdot}$$

Ozonation of *t*-butylamine in isobutane and isooctane gave largely the nitroisobutane (V, eq 7). The best results were obtained in isooctane (expt 9, Table I) from which azoxyisobutane (XV) also was isolated. This probably arises from interaction of *t*-butylhydroxylamine and nitrosoisobutane (eq 28). This summed with twice eq 1 and 4, eq 5, and two times eq 7 gives eq 29, which fits fairly well the stoichiometry of expt 9. The extra ozone reacting accounts for the alcohol side product (also found in expt 8). Since there was no apparent reaction between ozone and the solvent alone at the reaction temperature of expt 8 and 9 of Table I, we suggest eq 3 and 30–32 as the origin of the

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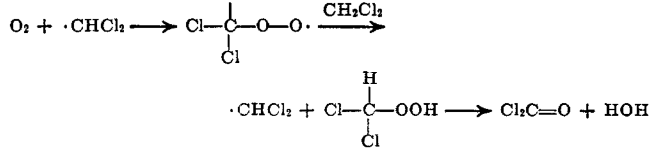
[16] An alternative explanation for the formation of phosgene is shown by the following equation, suggested by the work of J. I. G. Codogan, D. H. Hey, and P. G. Hibbert, *J. Chem. Soc.*, 3939 (1959).

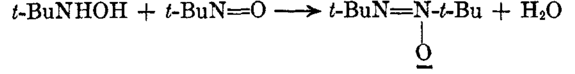


$$O_2 + \cdot CHCl_2 \longrightarrow Cl-\underset{Cl}{\overset{H}{C}}-O-O\cdot \xrightarrow{CH_2Cl_2} \cdot CHCl_2 + Cl-\underset{Cl}{\overset{H}{C}}-OOH \longrightarrow Cl_2C{=}O + HOH$$

[17] W. J. Lautenberger, E. N. Jones, and J. G. Miller, *J. Amer. Chem. Soc.*, **90**, 1110 (1968).

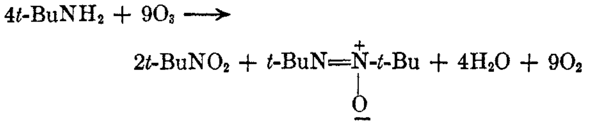
[18] (a) A. K. Hoffmann, W. G. Hodgson, D. L. Maricle, and W. H. Jura, *ibid.*, **86**, 631 (1964); (b) G. Chapelet-Letourneux, H. Lemaire, and A. Rassat, *Bull. Soc. Chim. Fr.*, 3283 (1965).

alcohol products. It is noteworthy that, although the amine plays a prominent role in this oxidation of the alkane, it is not used up in the series of reactions.



$$t\text{-BuNHOH} + t\text{-BuN=O} \longrightarrow t\text{-BuN}=\underset{\underset{\bar{O}}{|}}{\overset{+}{N}}\text{-}t\text{-Bu} + H_2O \qquad (28)$$

XV



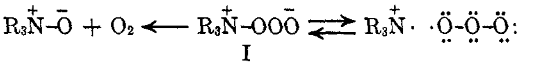
$$4t\text{-BuNH}_2 + 9O_3 \longrightarrow 2t\text{-BuNO}_2 + t\text{-BuN}=\underset{\underset{\bar{O}}{|}}{\overset{+}{N}}\text{-}t\text{-Bu} + 4H_2O + 9O_2 \qquad (29)$$

$$\underset{\text{VIIa}}{t\text{-Bu}\dot{N}H_2} + RH \longrightarrow t\text{-Bu}\overset{+}{N}H_3 + \cdot R \qquad (30)$$

$$R\cdot + \cdot O_3^- \longrightarrow ROOO^- \longrightarrow RO^- + O_2 \qquad (31)$$

$$RO^- + t\text{-Bu}\overset{+}{N}H_3 \longrightarrow ROH + t\text{-BuNH}_2 \qquad (32)$$

Thus, the results of ozonation of *t*-butylamine in the various solvents furnish strong evidence for two different fates of an initial amine–ozone adduct, as summarized by general eq 33. The results in carbon tetrachloride, in which an ammonium salt is produced even though the solvent does not contain hydrogen, and in isooctane, in which the solvent is converted into an alcohol even though it does not react with ozone alone, constitute especially strong evidence for nitrogen cation radical intermediates. The dissociation of I to cation and anion radicals, however, appears to become important only if the nitrogen cation radical is stabilized by resonance, as with Wurster's salts,[3] or can readily abstract a hydrogen atom from its environment.



$$R_3\overset{+}{N}\text{-}\bar{O} + O_2 \longleftarrow R_3\overset{+}{N}\text{-}OO\bar{O} \rightleftarrows R_3\overset{+}{N}\cdot \;\cdot\ddot{\underset{..}{O}}\text{-}\ddot{\underset{..}{O}}\text{-}\ddot{\underset{..}{O}}:$$

I

Registry No.—III, 16649-50-6; IV, 917-95-3; VI, 75-64-9; XV, 16649-52-8.

Acknowledgments.—This work was supported by grants from the National Science Foundation, the Robert A. Welch Foundation, and the Petroleum Research Fund of the American Chemical Society, for which the authors are very grateful.

Regiospecificity. A Useful Terminology in Addition and Elimination Reactions[1]

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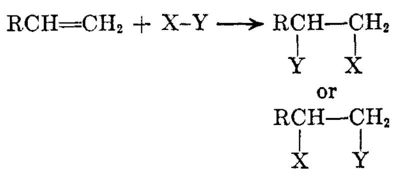
Received January 22, 1968

The prefix *regio* is proposed to complement that of *stereo* to describe orientational or directional preference in reaction specificity and selectivity involving bond making or breaking. Examples of regiospecific and regioselective additions, eliminations, ring opening, and cycloadditions are discussed.

The terms stereospecificity and stereoselectivity[2] are deeply entrenched in the chemical vocabulary, particularly in that of the organic chemist. While these terms are useful in describing stereochemical preference in organic reactions, namely, the propensity to a certain relative spatial arrangement of reacting groups (*e.g. cis* or *trans* additions), there seems to be no general term in use for describing selectivity or specificity of orientational or directional preference in chemical reactions.

For instance the addition of an unsymmetrical reagent X–Y to an unsymmetrical olefin $RCH{=}CH_2$ often occurs in a highly specific manner, with one segment of the reagent (*i.e.*, X) being directed to assume one of two possible positions in the final product (eq 1 and 2).



$$RCH{=}CH_2 + X\text{–}Y \longrightarrow \underset{\displaystyle Y}{\underset{|}{RCH}}\text{—}\underset{\displaystyle X}{\underset{|}{CH_2}} \qquad (1)$$

or

$$\underset{\displaystyle X}{\underset{|}{RCH}}\text{—}\underset{\displaystyle Y}{\underset{|}{CH_2}} \qquad (2)$$

The problem is a general one, namely, that of describing the preferential making or breaking of bonds in one of two possible orientations.

We have proposed that the course of such reactions be referred to as *regiospecific*,[3] the term being derived from the latin ward *regio* denoting direction. Regiospecificity then refers to the directional preference of bond formation. If a reaction proceeds without skeletal rearrangement to give exclusively (within experimental error) one of two or more possible isomers, it is called *regiospecific*. If there is a significant preponderance of one isomer formed it is said to be *regioselective*.[4] A nearly equimolar isomer distribution is the result of a *nonregiospecific* reaction.

These terms are useful not only in addition reactions but equally in a variety of chemical processes including eliminations, ring opening, and cycloaddition reactions as illustrated below.

Although regiospecificity, like stereospecificity, describes an important characteristic of reactions by itself, selected modifying terms can greatly enhance the definition of such reactions. The terms Markovnikov[5] and anti-Markovnikov to modify the type of regiospecificity are archaic and sometimes inadequate. For instance the ionic addition of hydrobromic acid to

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[1] Stereochemistry. XXXIV. For paper XXXIII, see F. W. Fowler and A. Hassner, *J. Amer. Chem. Soc.*, **90**, 2875 (1968).

[2] E. L. Eliel, "Stereochemistry of Carbon Compounds," McGraw-Hill Book Co., New York, N. Y., 1962.

[3] (a) A. Hassner, and F. Boerwinkle, *J. Amer. Chem. Soc.*, **90**, 216 (1968). (b) The pronunciation *reejio* is proposed. (c) The need for such a term has recently also been recognized by H. G. Viehe [*Angew. Chem. Intern. Ed. Eng.*, **6**, 767 (1967)] who proposed the slightly more cumbersome term directiospecific.

[4] Unlike in stereospecificity where one is faced with the problem of two isomeric substrates leading to the same product, in regiospecificity one deals with only one substrate leading to two (or more) possible regioisomers. This permits the designation regioselectivity to be used for partial regiospecificity.

[5] V. W. Markovnikov, *Compt. Rend.*, **81**, 668 (1875).