nmr spectrum that was in complete accord with the structure assigned. Crystallization could not be induced by seeding the oil with a crystal of the corresponding ketone from the ivalbin series. There was no trace of xanthinin in the crude products of this oxidation reaction (by tlc).

Anhydrodehydroivalbin (7) from Isoxanthanol—The oily ketone (6, 20 mg) was chromatographed in ether solution over a column of alumina (Woelm, activity II). The eluate was evaporated and the residue recrystallized from ether–hexane to yield colorless needles of the dienone (VI): mp 117–118°; $[\alpha]^{25}_{D}$ 63° (*c* 0.23, chloroform) [lit.[5] mp 117–118°; $[\alpha]_{D}$ 59° (*c* 0.195, chloroform)]. A mixture melting point with a specimen of anhydrodehydroivalbin was undepressed, and the two materials showed identical behavior on tlc.[9] The uv spectrum showed λ_{max} 244 mμ (ε 12,300) [lit.[6] λ_{max} 245 mμ (13,000)].

Extraction of Assay Specimens (Table I). 1.—A sample of 20 g of dried, ground leaves of *X. strumarium* (no. 91667-X-SY) was extracted with chloroform and the solvent removed. The tarry residue was dissolved in 10 ml of ethanol to which was added 50 ml of hot water. The clear aqueous portion was decanted from tar, treated with a few drops of lead acetate, clarified by filtration through Celite, and extracted with chloroform. The chloroform layer showed a single spot on tlc. Evaporation of the solvent left a gum which crystallized when ether was added. The product was collected and washed with cold ether; it formed colorless needles, mp 98–99° (250 mg).

2.—A 160-g sample of *X. strumarium* (no. 10867-X-SA) was worked up in the same way. The residue from the last chloroform extract yielded 2.35 g of crystals which had mp 112–114°. Mixture with pure xanthinin (mp 126°) gave a melting point of 116–120°, and with xanthumin (mp 99–100°) gave a melting point of 95–97°. One recrystallization from ethanol raised the melting point to 118–119°.

The ether mother liquors from the first crop of crystalline material were evaporated and the residual oil covered with ether and placed in the refrigerator. The crystals which separated were collected and recrystallized several times, yielding 0.44 g of pure xanthumin, mp 99–100°.

(−)-(*S*)-Methylsuccinic Acid. A. From Xanthinin.—To 500 mg of xanthinin was added 20 ml of a solution prepared by dissolving 34 g of chromic oxide in 200 ml of water and 20 ml of concentrated sulfuric acid. The solution was refluxed for 2.3 hr, cooled, and extracted continuously with ether. The ether extract was dried and evaporated and the oily residue dissolved in benzene. The crystalline product (65 mg) that separated was recrystallized from benzene to give 58 mg of methylsuccinic acid, mp 110–111°. A mixture of this material with authentic (±)-methylsuccinic melted at 108–111°. The rotation was $[\alpha]^{26}_{D}$ 7.7° (*c* 3.64, H_2O). The nmr spectrum of the compound was identical with that of the authentic material.

B. From Xanthumin.—The same procedure was used for the oxidation of 500 mg of xanthumin to yield 50 mg of methylsuccinic acid, mp 110.5–111°. A mixture melting point of the two acids from the natural sources was undepressed. The rotation was $[\alpha]^{26}_{D}$ 5.5° (*c* 2.04, H_2O).[10]

Registry No.—**1**, 17954-90-4; **3**, 17976-42-0; **4**, 17954-91-5; **5**, 17968-60-4; **7**, 17968-61-5; (−)-(*S*)-methylsuccinic acid, 2174-58-5.

Acknowledgments.—This work was supported by a Grant GM-14240-02 from the U. S. Public Health Service. Analyses were by Miss Heather King, UCLA. We are grateful to Professor W. W. Payne for plant material and valuable consultation and to Professor Werner Herz for specimens of compounds of the ivalbin series.

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[9] Specimens of acetyldehydroivalbin and anhydrodehydroivalbin were kindly provided by Professor W. Herz.

[10] The polarimetry was checked by measuring the rotation of xanthinin, $[\alpha]^{26}_{D}$ 54.5° (lit.[1] $[\alpha]^{26}_{D}$ 52°). Since the melting point of pure (−)-(*S*)-methylsuccinic acid is reported to be 115°, some racemization took place during the oxidation. M. Matell [*Arkiv. Kemi*, **5**, 17 (1952)] reported $[\alpha]^{23}_{D}$ 6.1° for methylsuccinic acid obtained by the oxidation of active 2-methyl-4-pentenoic acid, from which it was calculated that the product was a mixture of 63% (−) and 37% (±) acid.

Thermal and Photochemical Rearrangements of Azine Oxides. I. A Novel Pyrolytic Decomposition to Nitriles

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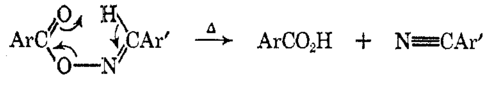
Received July 18, 1968

An investigation of the pyrolytic decomposition of aldazine monoxides has led to the discovery of a new eliminative process which results in fragmentation of the monoxide to 1 equiv each of nitrile and oxime. A new, easy process for preparing pure aromatic azine monoxides in good yields, utilizing CF_3CO_3H as the oxidizing agent in a buffered solution, is described and discussed along with attempts to extend such preparations to aliphatic systems. An unsymmetrical azine oxide is prepared and characterized for the first time, and its pyrolysis is discussed.

Pyrolyses of either benzoyl-α-benzaldoximes, **1**,[1] amine oxides, **2**,[2] or nitronate esters, **3**[3] (eq 1–3), result cleanly in elimination processes, ostensibly *via* cyclic transition states as shown below. Aldazine monoxide systems, on the other hand, while bearing much analogy to the above systems, have been reported[4] upon pyrolysis to fragment as in eq 4 to aldehydes and diazo compounds, presumably *via* oxazirane intermediates.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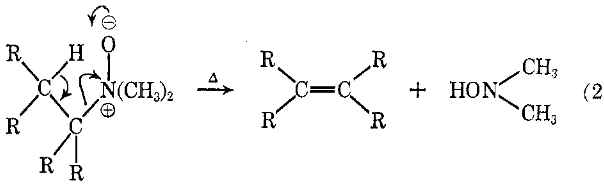
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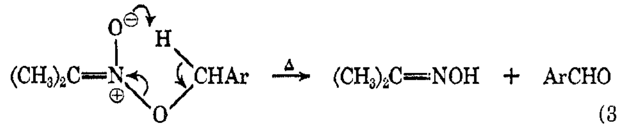
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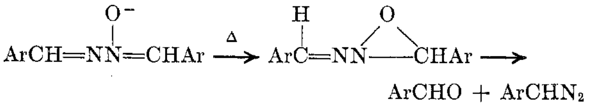
(4)

$$\mathrm{ArCH{=}N\overset{O^-}{\overset{|}{N}}{=}CHAr \xrightarrow{\Delta} Ar\overset{H}{\overset{|}{C}}{=}NN\overset{O}{\frown}CHAr \longrightarrow ArCHO + ArCHN_2} \quad (4)$$

We wish at this time to present some results from our current research into the chemistry of azine oxides.

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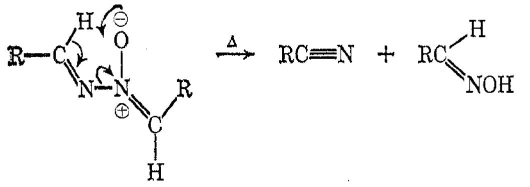
[1] J. H. M. Hill and L. D. Schmookler, *J. Org. Chem.*, **32**, 4025 (1967).

[2] A. C. Cope and E. R. Trumbull, *Org. Reactions*, **11**, 361 (1960).

[3] H. B. Hass and M. L. Bender, *J. Amer. Chem. Soc.*, **71**, 1767 (1949).

[4] L. Horner, W. Kirmse, and H. Fernekess, *Chem. Ber.*, **94**, 279 (1961).

While ketazine monoxides, such as benzophenone azine monoxide, **4**, were found indeed to rearrange thermally[5] as described in eq 4, aldazine monoxides **5a** and **b** did not, but rather fragmented *via* apparent five-membered transition states to produce nitriles and aldoximes as in eq 5. No nitrogen evolution was



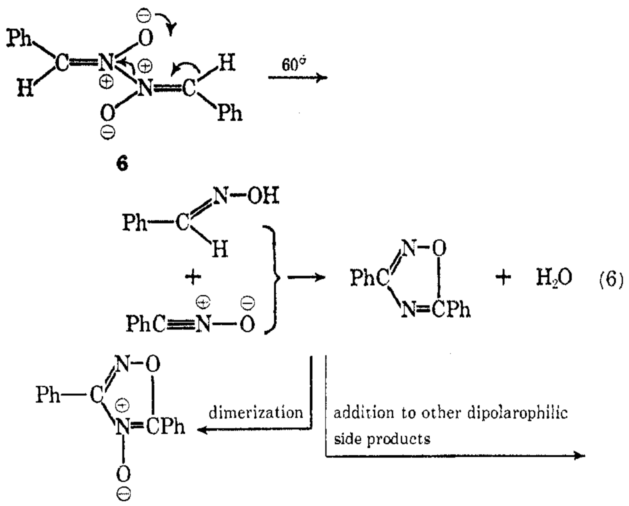
(5)

5a, R = C_6H_5
b, R = 2-furyl

observed, and no aldehydes were detectable in the product mixtures by gas chromatography.

These results deviate, of course, from those reported earlier.[4] Indeed, a mixture of benzonitrile and benzaldoxime could easily have been mistaken by these workers for benzaldehyde as it was characterized in the earlier report. All products in our studies were identified by gas chromatographic retention times and comparison of their physical properties, nmr, ir, and mass spectra with those of authentic samples.

It also now seems clear that the bulk of the literature[6] dealing with the thermal reactions of what now appears to be the bisoxide of benzaldazine, **6**,[7] can also be best understood by hypothesizing a similar eliminative first step in its decomposition. Upon heating **6** gently in $CHCl_3$, a near-quantitative isolation of benzaldoxime was possible.

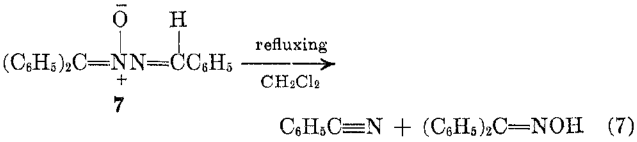


(6)

The demonstration, by Horner, Hockenberger, and Kirmse,[7] of the structure of **6** after almost 80 years of confusion, coupled with their studies of its photochemical reactions and our findings above, enable one to begin to assemble a pretty good impression of what is going on in this complicated system.

An improved method of preparing the azine monoxides was also developed during the course of this study. They could be prepared, uncontaminated by residual azine or bisoxide, in good yields by treating a solution of the appropriate azine in ether, containing excess Na_2CO_3 as a buffering agent, at 0°, with 2 equiv of peroxytrifluoroacetic acid. In all cases, yields were greatly improved and the time of reaction was drastically shortened compared with the previous method of preparation.[4]

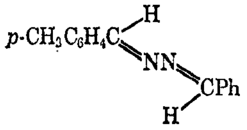
An unsymmetrical azine monoxide, N-benzylidene-N′-diphenylmethyleneazine N′-oxide, **7**, was prepared for the first time. Its structure was unambiguously



$$\underset{\mathbf{7}}{(C_6H_5)_2C{=}\overset{\overset{\bar{O}}{|}}{\underset{+}{N}}N{=}\overset{\overset{H}{|}}{C}C_6H_5} \xrightarrow[CH_2Cl_2]{\text{refluxing}} C_6H_5C{\equiv}N + (C_6H_5)_2C{=}NOH \quad (7)$$

established by spectroscopic and chemical data. A singlet in the nmr spectrum at τ 0.65 for the only nonaromatic proton indicates that a single azine monoxide has been produced. Symmetrical aldazine monoxides (such as benzaldazine N-oxide) always exhibit two well-separated singlets (τ 0.60 and 2.2) of equal intensity for the two nonaromatic protons. The mass spectral cracking pattern showed major fragments of *m/e* 103, 180 and 197 as well as the parent ion. In addition, the pyrolysis results (eq 7) and acid-catalyzed hydrolysis of **7** to benzophenone free of benzaldehyde are consistent with our assignment of structure.[4] The exclusive formation of the single azine monoxide from the oxidation can perhaps best be rationalized in terms of the better delocalization of the partial positive charge in the transition state by a benzhydryl system than by a benzyl system.[8]

Attempts were made to synthesize specifically other aromatic unsymmetrical azine monoxides from unsymmetrical azines such as 4-methylbenzylidenebenzylidene azine, **9**, but mixtures of both possible azine oxides were obtained. In the case of **9**, nmr spectra indicated that close to a 50:50 mixture was obtained.



9

All attempts to prepare and study aliphatic aldazine monoxides were unsuccessful. Mixing of the preparative reagents resulted either in no reaction at all (below −20°) or in rapid evolution of nitrogen concomitant with formation of the appropriate aldehyde and ester. At no time was the oxide able to be detected as an intermediate.[10]

Attempted oxidation of mixed aromatic and aliphatic unsymmetrical azines, such as isopropylidenediphenylmethyleneazine, **10**, resulted in formation of no detectable amount of oxides but only in an apparent immediate transitory formation of diphenyldiazomethane as evidenced by the deep red color of the solu-

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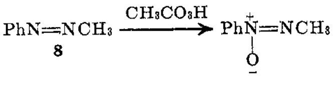
[5] This reaction was first studied by W. M. Lauer and W. S. Dyer, *J. Amer. Chem. Soc.*, **64**, 1453 (1942).

[6] E. Beckmann, *Ber.*, **22**, 1588 (1889); P. Robin, *Ann. Chim.*, **16**, 77 (1921); J. H. Boyer and H. Alul, *J. Amer. Chem. Soc.*, **81**, 4237 (1959), and references therein.

[7] L. Horner, L. Hockenberger, and W. Kirmse, *Chem. Ber.*, **94**, 290 (1961).

[8] A similar argument may also be used to explain the analogous oxidation of benzeneazomethane, **8**, in which oxidation is almost exclusively adjacent to the phenyl group.[9]

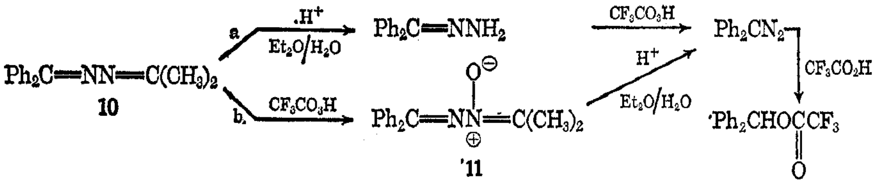


$$\underset{\mathbf{8}}{PhN{=}NCH_3} \xrightarrow{CH_3CO_3H} Ph\overset{+}{\underset{\underset{\bar{O}}{|}}{N}}{=}NCH_3$$

[9] J. P. Freeman, *J. Org. Chem.*, **28**, 2508 (1963).

[10] By mixing the reagents below −20° and scanning the nmr spectrum of the mixture while the tube was slowly allowed to warm to room temperature, no oxide intermediate was able to be detected.

tion. The diazo species were trapped by carrying out the reaction in the presence of an excess of trifluoroacetic acid. Isolation of the ester product in quantitative yield indicated that no dimethyldiazomethane had been formed in the oxidation reaction. These results could equally well be explained by either of the alternative pathways depicted in eq 8. The inability to observe monoxide **11** directly, while certainly not ruling out its transient existence, demands that we consider also the alternative process involving hydrolysis prior to oxidation.[11]



(9)

Experimental Section

Melting points are uncorrected. Analyses were determined by Peninsular ChemResearch Inc., Gainesville, Fla. The glpc analyses were carried out on a Varian Aerograph Model A-90-P3 gas chromatograph combined with a Leeds and Northrup Model H recorder equipped with a Disc integrator using 0.25 in. × 6 ft 10% Carbowax 20M on Chromosorb P column. Ir spectra were recorded with a Perkin-Elmer Model 137 spectrophotometer, KBr prism; nmr spectra on a Varian Model A-60-A spectrometer, utilizing TMS as an internal standard; mass spectra on a Hitachi Perkin-Elmer RMU-6E mass spectrometer; and uv spectra on a Cary Model 15 spectrometer.

Benzaldazine Monoxide (5a).—To 6.24 g (0.03 mol) of benzaldazine[12] in 70 ml of Et_2O was added 22.3 g (0.21 mol) of solid Na_2CO_3, and the stirred mixture was treated at 0° over a period of 1 hr with 0.06 mol of CF_3CO_3H.[13] After stirring for 2 hr at 0°, H_2O and Et_2O were added to dissolve all solids. The ether layer was washed once with 15% aqueous K_2CO_3, three times with H_2O, and dried with anhydrous $MgSO_4$ and the volatile materials were evaporated. The solid residue was washed with pentane and recrystallized from 95% EtOH to yield 5.6 g (83.3%) of pale yellow crystals: mp 130–131° (lit.[4] mp 131°); λ_{max} (EtOH) 340 mμ (ϵ 25,700), 275 (12,200), 224 (8070); ir ($CHCl_3$) 3020, 2980, 1625, 1580, 1550, 1445, 1405, 1205, 1090, 1075 and 687 cm^{-1}; nmr (CH_2Cl_2) τ 0.60 (s, 1), 1.74 (m, 2), 2.16 (m, 2) 2.20 (s, 1), and 2.58 (m, 6).

2-Furfuraldazine Monoxide (5b).—To 2.8 g (0.015 mol) of 2-furfuraldazine in 70 ml of Et_2O was added 11.2 g (0.11 mol) of Na_2CO_3 and the stirred mixture treated as above with 0.029 mol of CF_3CO_3H. After the usual work-up, the product was recrystallized from 75% EtOH to yield 2.3 g (77%) of orange-yellow needles: mp 147–148° (lit.[4] mp 181°); ir (CH_2Cl_2) 3000, 1625, 1575, 1550, 1475, 1460, 1390, 1205, 1085, 1080, 1025, 1015, 940, 885, 835 and 830 cm^{-1}; nmr (CH_2Cl_2) τ 0.82 (s, 1), 2.10 (s, 1) 2.30 (m, 3), 2.86 (m, 1), and 3.40 (m, 2).

Anal. Calcd for $C_{10}H_8N_2O_3$: C, 58.82; H, 3.95; N, 13.72. Found: C, 58.66; H, 4.1; N, 13.85.

N-Benzylidene-N′-diphenylmethyleneazine N′-Oxide (7).—A mixture of 4.1 g (0.0145 mol) of benzylidenediphenylmethyleneazine and 10.6 g (0.1 mol) of Na_2CO_3 in 50 ml of Et_2O was treated as above with 0.029 mol of CF_3CO_3H. After the usual work-up the light yellow solid was washed with two 30-ml portions of cold Et_2O to yield 3.2 g (75%): mp 114°; ir (CH_2Cl_2) 3000, 1600, 1580, 1520, 1500, 1440, 1235, 1220, 1135, and 965 cm^{-1}; nmr (CH_2Cl_2) τ 0.65 (s, 1), 2.00 (m, 2), and 2.58 (m, 13).

Anal. Calcd for $C_{20}H_{16}N_2O$: C, 80.00; H, 5.33; N, 9.33. Found: C, 79.70; H, 5.48; N, 9.34.

Acid-Catalyzed Hydrolysis of 7.—A solution of 0.5 g of **7** in 10 ml of EtOH was warmed with 1 drop of 3.6 *N* H_2SO_4. Gas evolution was immediately evident and the yellow solution soon became colorless. After neutralization with saturated K_2CO_3 solution, extraction with Et_2O, and drying over $MgSO_4$, gas chromatographic analysis clearly indicated the presence of benzophenone and the absence of benzaldehyde.

Benzophenoneazine Monoxide (4).—A mixture of 2.0 g (0.00555 mol) of benzophenoneazine and 2.0 g (0.019 mol) of Na_2CO_3 in 250 ml of Et_2O, was treated as above with 0.021 mol of CF_3CO_3H. After the usual work-up, 2.0 g of the oxide, slightly contaminated by unreacted azine, was obtained. Elution chromatography (silica gel–CCl_4) washes out the impurity and the bright yellow oxide was eluted with acetone. Recrystallization from EtOH yielded 1.9 g (91%) of pure oxide: mp 157° (lit.[4] mp 157°); ir (CH_2Cl_2) 2990, 1590, 1555, 1510, 1500, 1440, 1420, 1340, 1310, 1300, 1245, 1180, 1145, 1070, 1040, 1000, 975, 965, 920, and 885 cm^{-1}; nmr (CH_2Cl_2) τ 2.70 (m).

Reaction of Isopropylidenediphenylmethyleneazine (10) with CF_3CO_3H in the Presence of Excess CF_3CO_2H.—The azine (2.36 g, 0.01 mol) in 70 ml of Et_2O containing 5 ml of CF_3CO_2H was treated dropwise with CF_3CO_3H in Et_2O at 0°. Addition was continued until nitrogen evolution ceased and no further red color was produced. About 60% of a solution prepared from 0.02 mol of H_2O_2 and 0.02 mol $(CF_3C{=}O)_2O$ was required. After the usual work-up, 2.8 g (100%) of a yellow oil was obtained (tlc indicated only a slight impurity). Distillation of the oil yielded 2.0 g (72%) of $CF_3CO_2CH(C_6H_5)_2$, bp 92–94° (3 mm), $n^{22}D$ −1.5039 [lit.[14] bp 93° (2.5 mm); $n^{25}D$ 1.500]. Ir, nmr, and mass spectra of the ester product were all consistent with the structure.

Pyrolyses of Azine Monoxides.—Pyrolyses were carried out under the conditions given in Table I, using 0.8–1.0-g samples, neat, or in 50 ml of the appropriate solvent. Products were isolated by elution chromatography (silica gel) used in conjunction with thin layer chromatography. All products were characterized by comparison of their gas chromatographic retention times, physical properties, and nmr, ir, and mass spectra with those of authentic samples. Yields were obtained by actual weight or by quantitative gas chromatography using an internal standard.

TABLE I

PYROLYSIS PRODUCTS OF AZINE MONOXIDES

Azine monoxide	Pyrolysis conditions	Products, %			
		Nitrile	Oxime	Ketone	Azine
4	160°, neat			52	53
5a	135°, neat	46	56		
5b	Refluxing toluene, 16 hr	70	67		
7	Refluxing CH_2Cl_2, 3 days	97	Quant		

Pyrolysis of Benzaldazine Bisoxide[6,7] (6).—A mixture of 1 g of **6** in 30 cc of $CHCl_3$ was warmed gently (but not boiled) on a steam bath until all solid was brought into solution. After warming for an additional 15 min, the solution was poured into water, washed, and dried. The $CHCl_3$ was evaporated to give a near quantitative yield of benzaldoxime.

Registry No.—5a, 18339-73-6; **5b**, 18339-74-7; **7**, 18409-51-3.

Acknowledgment.—We wish to express our deep appreciation to the donors of the Petroleum Research Fund, administered by the American Chemical Society, for their support of this research through Research Grant 753 G.

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[11] L. Horner and H. Fernekess, *Chem. Ber.*, **94**, 712 (1961).

[12] For general methods of preparing both symmetrical and unsymmetrical azines, see D. Kolbah and D. Korunčev in Houben-Weyl's "Methoden der organischen Chemie," Vol. X/2, E. Muller, Ed., Georg Thieme Verlag, Stuttgart, 1967.

[13] W. D. Emmons and A. S. Pagano, *J. Amer. Chem. Soc.*, **77**, 89 (1955).

[14] C. A. Bunton and T. Hadwick, *J. Chem. Soc.*, 943 (1961).