of the area of capillary to total volume was 8.24–10.52 × 10^{-4} cm.$^{-1}$ for the dilatometers used in the study. Samples were degassed before each run using high vacuum technique.

Reaction of R-R' with Butyl Mercaptan.—The reaction was observed in the course of attempts to use the mercaptan as a scavenger for radicals produced in the decomposition of R-R'. Solutions initially containing about 0.016M R-R' and about 0.9M mercaptan in benzene and carbon tetrachloride showed only 2–6% residual R-R' by infrared analysis after heating for one hour at 80°. In similar experiments in which the initial concentration of mercaptan was 0.04M the apparent first-order rate constant for disappearance of R-R' was increased by factors of 2–3. Insufficient data were gathered to permit quantitative documentation of the rate law involved or to resolve the "true" unimolecular contribution to the rates. The reaction products were not isolated.

Acknowledgment.—This work was supported by a grant from the National Science Foundation. Infrared spectroscopic service was provided by the Iowa State Institute for Atomic Research. We are especially indebted to Messrs. E. Miller Layton and Richard Knisely for programming infrared analyses.

AMES, IOWA

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY OF PURDUE UNIVERSITY]

Preparation of α-Nitroketones. C-Acylation of Primary Nitroparaffins[1]

BY G. BRYANT BACHMAN AND TAKEO HOKAMA[2]

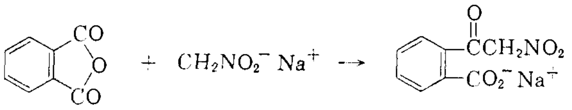
RECEIVED DECEMBER 27, 1958

C-Acylation of primary nitroparaffin salts to form α-nitroketones has been accomplished with the aid of acyl cyanides in 30–70% yields. No α-nitroketones were obtained from salts of secondary nitroparaffins. The mechanisms of acylations by acyl cyanides and by acid halides are discussed.

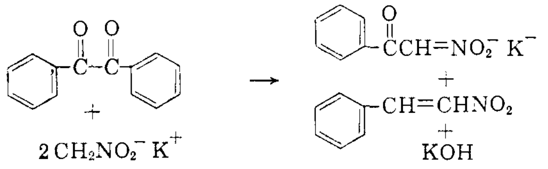
The nitroparaffins have attracted considerable theoretical interest since their initial discovery because of the ambivalency of their corresponding anions which permits substitution reactions to occur either at the oxygen of the nitro group or at the carbon attached to the nitro group. Numerous workers have investigated the acylation of nitroparaffins using acid halides,[3] acid anhydrides,[4] ketene,[3e,5] acylpyridinium chlorides[6] and acid esters[7] under a variety of conditions.

In all but one case, initial O-acylation was observed to occur exclusively with subsequent rearrangement of the nitronic anhydrides formed to acylated hydroxamic acids from primary nitroparaffins. A logical sequence of reactions for these paraffins and to nitroso acyloxy compounds from secondary nitro rearrangements has recently been proposed.[8]

The only case of C-acylation by an acid derivative was that reported by Gabriel[4a] in 1903 when he obtained poor and inconsistent yields of 2-(nitroacetyl)-benzoic acid from the reaction of phthalic anhydride with sodium methanenitronate in ether. Another exceptional case in which an α-nitroketone was obtained from a carbonyl compound (not an acid derivative) was reported by Jakubowitsch.[9] He obtained nitroacetophenone from the reaction of benzil with nitromethane in the presence of two molar equivalents of alcoholic potassium hydroxide.



(1)



(2)

We have found that C-acylation of primary nitroparaffins can be accomplished with acyl cyanides[10] under basic conditions. α-Nitroketones are obtained in 30–70% yields. No C-acylated product was obtained from secondary nitroparaffins although numerous attempts to do so were made under a variety of conditions. The results of these investigations are summarized in Tables I and II.

Discussion of Results

Good yields of α-nitroketones are highly dependent on various factors but especially on suitable solubilities of the reactants and on the suppression of side reactions which consume the acylating agent faster than the desired reaction. As a better understanding of these factors was gained through systematic evaluations of them, it became possible to formulate a mechanism for the reaction and to explain the suitability of acyl cyanides as acylating agents for nitroparaffins.

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(1) Taken from a thesis submitted by T. Hokama to the faculty of the Graduate School of Purdue University in partial fulfillment of the requirements for the Ph.D. degree, August, 1958.

(2) American Cyanamid Fellow, 1957–1958.

(3) (a) J. Kissel, *Ber.*, **15**, 727 (1882); (b) L. W. Jones, *Am. Chem. J.*, **20**, 1 (1897); (c) A. F. Holleman, *Rec. trav. chim., France*, **15**, 356 (1896); (d) A. van Raalte, *ibid.*, **18**, 378 (1899); (e) D. A. Isacescu and C. D. Nenitzescu, *Bull. soc. chim. Romania*, **14**, 53 (1953); (f) H. Wieland and Z. Kitasato, *Ber.*, **62**, 1252 (1929); (g) H. Wieland and A. Hochtlen, *Ann.*, **505**, 237 (1933); (h) J. T. Thurston and R. L. Shriner, *J. Org. Chem.*, **2**, 183, 560 (1937); (i) W. Wislicenus and K. Pfeilsticker, *Ann.*, **436**, 40 (1924).

(4) (a) S. Gabriel, *Ber.*, **36**, 570 (1903); (b) M. G. Foster, *J. Chem. Soc.*, **77**, 251 (1900); (c) T. Urbanski, *ibid.*, 3374 (1949); (d) E. P. Stefl and M. F. Dull, THIS JOURNAL, **69**, 3037 (1947).

(5) T. Urbanski and W. Gurzynska, *Roczniki Chem.*, **25**, 183 (1951); *C. A.*, **46**, 7994 (1952).

(6) R. H. Terss and W. E. McEwen, THIS JOURNAL, **76**, 580 (1954).

(7) R. Lin, M.S. Thesis, Purdue University, 1956.

(8) E. H. White and W. J. Considine, THIS JOURNAL, **80**, 626 (1958).

(9) A. J. Jakubowitsch, *J. prakt. Chem.*, **142**, 37 (1935).

(10) The use of acyl cyanides as acylating agents for other types of active methylene compounds was first reported by A. Dornow and H. Grabhöfer, *Chem. Ber.*, **91**, 1824 (1958).

TABLE I

ACYLATION OF NITROPARAFFINS WITH ACYL CYANIDES

	Nitroparaffin salt	Acyl cyanide	Time, hr.	Temp., °C.	Solvent	Products	Yield, %
1	$CH_3NO_2 + Na_2CO_3$	C_6H_5COCN	4.0	25	Pyridine	$C_6H_5COCH_2NO_2$	73
2	$C_2H_4NO_2^-\ Li^+$	C_6H_5COCN	4.0	25	*t*-Butyl alc.	$C_6H_5COCH(NO_2)CH_3$	50
3	$C_2H_4NO_2^-\ Li^+$	CH_3COCN	4.0	25	*t*-Butyl alc.	$CH_3COCH(NO_2)CH_3$	30
4	1-$C_3H_6NO_2^-Na^+$	C_6H_5COCN	5.0	25	*t*-Butyl alc.	$C_6H_5COCH(NO_2)C_2H_5$	26
						$C_6H_5CO_2H$	33
5	1-$C_3H_6NO_2^-Na^+$	C_6H_5COCN	12.0	25	Pyridine	C_6H_5COCN	67
						$C_6H_5CO_2H$	10
6	1-$C_3H_6NO_2^-Na^+$	C_6H_5COCN	12.0	60	Tetrahydrofuran	C_6H_5COCN	30
						$C_6H_5CO_2H$	49
7	1-$C_3H_6NO_2^-Li^+$	C_6H_5COCN	4.0	25	*t*-Butyl alc.	$C_6H_5COCH(NO_2)C_2H_5$	62
8	1 $C_3H_6NO_2^-Li^+$	C_6H_5COCN	8.0	25	Pyridine	$C_6H_5COCH(NO_2)C_2H_5$	54
9	1-$C_3H_6NO_2^-Li^+$	C_6H_5COCN	8.0	25	Tetrahydrofuran	$C_6H_5COCH(NO_2)C_2H_5$	60
			1.0	65			
10	1-$C_3H_6NO_2^-Li^+$	CH_3COCN	4.0	25	*t*-Butyl alc.	$CH_3COCH(NO_2)C_2H_5$	36
11	2-$C_3H_6NO_2^-Li^+$	C_6H_5COCN	6.0	25	*t*-Butyl alc.	$C_6H_5CO_2C(CH_3)_2$	44
						$C_6H_5CO_2N{=}C(CH_3)_2$	17
12	1-$C_4H_8NO_2^-Li^+$	C_6H_5COCN	5.0	25	*t*-Butyl alc.	$C_6H_5COCH(NO_2)C_3H_7$	53
13	1-$C_4H_8NO_2^-Li^+$	CH_3COCN	4.0	25	*t*-Butyl alc.	$CH_3COCH(NO_2)C_3H_7$	38

TABLE II

PROPERTIES AND ANALYSES OF α-NITROKETONES

Compound	B.p., °C.	Mm.	$n^{25}D$	Formula	Analyses, % Calcd.	Analyses, % Found	2,4-Dinitrophenylhydrazone, m.p., °C
Nitroacetophenone[a]	105–106[d]			$C_8H_7NO_3$	C 58.18	58.20	
					H 4.27	4.27	
					N 8.48	8.52	
α-Nitropropiophenone	124	2	1.5434	$C_9H_9NO_3$	C 60.33	60.28	178
					H 5.06	5.40	
					N 7.82	8.12	
α-Nitrobutyrophenone	112–114	1	1.5334	$C_{10}H_{11}NO_3$	C 62.16	62.17	159
					H 5.74	6.00	
					N 7.25	7.49	
α-Nitrovalerophenone	48[d]			$C_{11}H_{13}NO_3$	C 63.75	63.56	133–134
					H 6.32	6.09	
					N 7.25	7.49	
2-Benzoyl-2-nitropropane[b]	108–110	1	1.5268	$C_{10}H_{11}NO_3$	C 62.16	62.17	161–162
					H 5.74	6.01	
					N 7.25	7.47	
3-Nitro-2-butanone	58	2	1.4362	$C_4H_7NO_3$			124 102[c]
3-Nitro-2-pentanone	52	1	1.4332	$C_5H_9NO_3$	C 45.79	46.00	110
					H 6.92	7.15	
					N 10.68	10.94	
3-Nitro-2-hexanone	60	1	1.4372	$C_6H_{11}NO_3$	C 49.64	50.68	82
					H 7.64	8.59	
					N 9.65	10.48	

[a] Jakubowitsch[9] reports m.p. 106°. [b] Prepared by chromic acid oxidation of corresponding nitroalcohol. [c] Anil: C. D. Hurd and M. E. Wilson, *J. Org. Chem.*, **20**, 926 (1955), report b.p. 71–75° (9 mm.), $n^{20}D$ 1.4349; 2,4-dinitrophenylhydrazone, m.p. 125°; anil, m.p. 101–102°. [d] Melting point.

The Acyl Cyanides.—An aromatic acyl cyanide, benzoyl cyanide, and an aliphatic acyl cyanide, acetyl cyanide, were used to establish the generality of the reaction. Slightly better yields were obtained with benzoyl cyanide than with acetyl cyanide.

Effect of the Metal Ion.—Lithium salts of the nitroparaffins were found to be better than sodium salts both from the standpoints of ease of preparation of the salts and of yields of α-nitroketones obtainable. Tenth molar amounts of lithium *t*-butoxide (0.33 *N*) may be prepared in 1–4 hours in refluxing *t*-butyl alcohol while sodium *t*-butoxide under the same conditions requires 12–14 hours. Furthermore the lithium salt of 1-nitropropane with benzoyl cyanide in *t*-butyl alcohol gave a 62% yield of the corresponding nitroketone whereas the sodium salt gave only a 26% yield.

The reason for the higher yields with the lithium salts probably lies in their greater solubility. That solubility is an important factor is indicated by the lack of success of the reaction in solvents in which the nitroparaffin salts are insoluble (*e.g.*, sodium salts in ethers).

The use of the silver and mercury salts of 2-nitropropane was studied to see whether the formation of insoluble silver cyanide and mercuric cyanide would promote C-acylation. The silver salt was found to be unstable[11] while the mercuric salt did not react, perhaps because it was too insoluble.

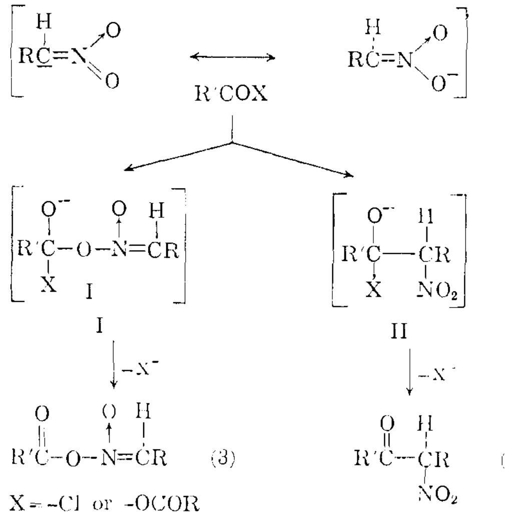
Effect of the Solvent.—The nitroparaffin salts have very limited solubilities in most organic solvents. One of the better types of solvent for these salts is the alcohols. However, in either ethanol or 2-propanol the reaction of the solvent with the acyl cyanide predominates and esters are the principal products. In *t*-butyl alcohol this competing solvent reaction is minimized by steric factors, and 30–70% yields of α-nitroketones are obtained.

In other attempts to eliminate the competing solvent reaction, non-hydroxylic solvents with high dielectric constants were investigated. With sodium alkanenitronates, no C-acylated products were obtained in dimethyl sulfoxide, dimethylformamide, pyridine, dioxane, tetrahydrofuran, 1,2-dimethoxyethane or ether, primarily because of the insolubility of the salts in these solvents. Successful C-acylation of the more soluble lithium 1-propanenitronate with benzoyl cyanide was observed in pyridine (54%), tetrahydrofuran (60%) and ether (10%).

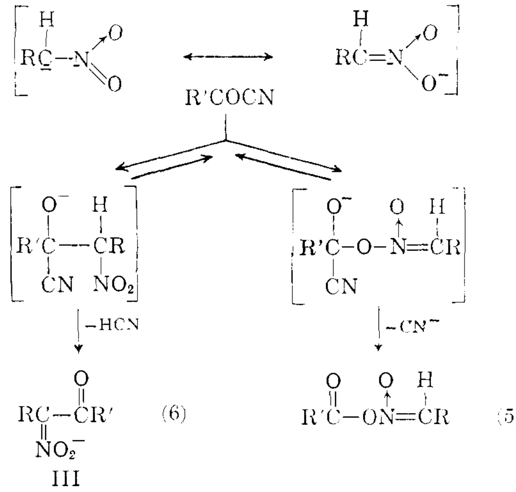
Nitromethane was benzoylated in pyridine in the presence of lithium or sodium carbonate. This procedure could not be extended to the higher homologs.

Mechanism of the Reaction.—The following rationalization may explain the difference in behavior of the acyl cyanides as compared to the acid halides and anhydrides. The nitronate ion is an "ambident anion"[12] and acylation can therefore occur either at an oxygen atom of the nitro group or at the carbon attached to the nitro group. Acylation at an oxygen would be favored by the greater inherent electronegativity of oxygen relative to carbon, by the statistical ratio of two available oxygen atoms to one carbon atom, and by the smaller steric requirements of a terminal oxygen atom. If the reaction occurred rapidly, these factors would be expected to predominate and lead to O-acylation. On the other hand, if the reaction occurred slowly enough for the equilibria involved to be established, then the above factors would be expected to be of lesser importance than the thermodynamic stabilities of the possible products, and C-acylation would be expected to predominate because the C-acylated product is the more stable thermodynamically.[13]

The two possible reaction paths for acylation of nitronate ions by acid halides or anhydrides may be represented by equations 3 and 4. Because of the large driving force provided by the loss of the weakly basic halide or carboxylate ion, this is a fast and irreversible reaction. Furthermore, since the carbonyl carbon of the acylating agent expands from trigonal bonding to tetrahedral bonding, the transition state is quite sensitive to the steric requirements of the nitroparaffin anion and on this basis also I would be favored over II. For these reasons O-acylation predominates.



In the case of the less reactive acyl cyanides, the greater basicity of the cyanide ion causes its elimination to be slower than the elimination of the chloride or carboxylate ions discussed above. The whole reaction is therefore slower and there is time for the establishment of all of the equilibria shown in equations 5 and 6. These are displaced toward the nitroketone by the favorable free energy change involved in the formation of the nitroketone anion with its high resonance energy stabilization. The formation of this ion provides the principal driving force for the reaction.



Therefore, the principal difference between the two types of acylation appears to lie in the fact that with acid halides and anhydrides both the O- and C-acylation reactions are essentially irreversible and proceed through unstable intermediates of different energy requirements, the one in the O-acylation process having a lower energy of formation than the one in the C-acylation process. With the acyl cyanides, O-acylation is superseded by C-acylation because the slowness of the reaction permits equilibration leading to the more thermodynamically stable product, the acylated nitronate ion III. It will be noted also that in both cases the least basic anion is formed preferentially, namely the chloride or acyloxy anion in equation 3 and the

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[11] A. Angeli and L. Alessandro, *Atti accad. Lincei*, **18**, 39 (1909); *C. A.*, **4**, 1739 (1910).

[12] N. Kornblum, R. A. Smiley, R. K. Blackwood and D. C. Iffland, This Journal, **77**, 6269 (1955).

[13] A. G. Catchpole, E. D. Hughes and C. K. Ingold, *J. Chem. Soc.*, 1 (1948).

nitroketonate anion in equation 6. Under the basic conditions of the reactions formation of these anions results in more favorable free energy changes in the same sense that reaction of base with hydrogen chloride, acetic acid or nitrous acid with liberation of chloride, acetate or nitrite ion is more favorable than reaction of base with hydrogen cyanide with liberation of cyanide ions. The conjugate acid of the nitroketonate anion is undoubtedly a considerably stronger acid than hydrogen cyanide.

Experimental

The following experiments illustrate the procedures employed.

α-Nitropropiophenone. Reaction of Benzoyl Cyanide with Lithium Ethanenitronate in *t*-Butyl Alcohol.—Nitroethane (7.8 g., 0.1 mole) was added to a solution of lithium *t*-butoxide formed by treating lithium metal (0.69 g., 0.1 mole) with *t*-butyl alcohol (dried over calcium hydride, 300 ml.) in a 500-ml., 3-necked flask equipped with a stirrer, dropping funnel and reflux condenser protected with a sodium hydroxide drying tube. Benzoyl cyanide (13 g., 0.1 mole) was added in 0.5 hr. to the cooled suspension, and the mixture was stirred for 4 hr. Most of the solvent was removed under vacuum and a mixture of ether, 100 ml., water, 200 ml., acetic acid, 10 g., and urea, 10 g., was added. The aqueous layer was separated and extracted with four 50-ml. portions of ether. The combined ether extracts were washed with water, dried, and distilled. α-Nitropropiophenone, b.p. 124° (2 mm.), $n^{26}\mathrm{D}$ 1.5434, 9.0 g. (50%), was isolated.

3-Nitro-2-butanone. Reaction of Acetyl Cyanide with Lithium Ethanenitronate in *t*-Butyl Alcohol.—Freshly distilled acetyl cyanide (17 g., 0.25 mole) was added in 2 hr. to a suspension of lithium ethanenitronate (20.2 g., 0.25 mole) in *t*-butyl alcohol (400 ml.) and the mixture was stirred for 4 hr. Most of the solvent was removed under water aspiration and a mixture of ether, 100 ml., water, 300 ml., acetic acid, 18 g., and urea, 10 g., was added. The aqueous layer was separated and extracted with four 50-ml. portions of ether. The combined ether layers were washed with water, dried and distilled. 3-Nitro-2-butanone, b.p. 58° (1 mm.), $n^{25}\mathrm{D}$ 1.4362, 11.6 g. (30% theory), was isolated.

Attempted Acylation of Lithium 2-Propanenitronate with Benzoyl Cyanide in *t*-Butyl Alcohol.—Benzoyl cyanide (20 g., 0.15 mole) was added in 0.5 hr. to a solution of lithium 2-propanenitronate (19 g., 0.2 mole) in *t*-butyl alcohol, 400 ml., and the mixture was stirred for 5.5 hr. The reaction mixture was poured into ice-water, 1.5 l., and extracted with six 100-ml. portions of ether. The combined ether layers were washed with water, dried and distilled. There were obtained *t*-butyl benzoate, b.p. 59° (1 mm.), $n^{26}\mathrm{D}$ 1.4658, 12.0 g. (44% theory); and acetone oxime benzoate, b.p. 124° (1 mm.), $n^{26}\mathrm{D}$ 1.5184, 8 g. (17% theory).

Anal. Calcd. for $C_{10}H_{11}NO_2$: C, 67.78; H, 6.27; N, 8.06. Found: C, 67.62; H, 5.82; N, 8.16.

The oxime benzoate gave benzanilide, m.p. 161°, upon treatment with aniline. Its infrared spectrum showed carbonyl absorption at 5.82 μ and C=N absorption at 6.02 μ.

α-Nitrobutyrophenone. Reaction of Benzoyl Cyanide with Lithium 1-Propanenitronate in Tetrahydrofuran.—Benzoyl cyanide (10 g., 0.077 mole) was added in 0.5 hr. to a suspension of lithium 1-propanenitronate (9.5 g., 0.1 mole) in purified tetrahydrofuran, 200 ml., and the mixture was stirred for 8 hr. at room temperature and 1 hr. at 65°. The reaction mixture was worked up by following the procedure given for α-nitropropiophenone. α-Nitrobutyrophenone, b.p. 128° (1 mm.), $n^{25}\mathrm{D}$ 1.5344, 9 g. (60% theory), was isolated.

Reaction of Benzoyl Chloride with Sodium 2-Propanenitronate.—Benzoyl chloride (15.6 g., 0.1 mole) was treated with sodium 2-propanenitronate (22.2 g., 0.2 mole) in ether, 200 ml. The reaction was relatively rapid and was complete in 2 hr. Benzoic acid, m.p. 120°, 11 g. (91% theory), was isolated.

Nitroacetophenone. Reaction of Benzoyl Cyanide with Nitromethane and Sodium Carbonate in Pyridine.—Benzoyl cyanide (13 g., 0.1 mole) was added in 0.5 hr. to a mixture of nitromethane (12 g., 0.2 mole) and sodium carbonate (21 g., anhydrous powder, 0.2 mole) in pyridine (dried over calcium hydride, 300 ml.) and the reaction mixture was stirred for 3.5 hr. The suspension was filtered and the precipitate was washed with dry ether (100 ml.). The solid was partially dissolved in water (400 ml.) and acidified with dilute hydrochloric acid (3 *N*, 200 ml.) at 0–5°. Nitroacetophenone, m.p. 105–106°, 12 g. (73% theory), was isolated by filtration, and recrystallized from petroleum ether (b.p. 65–67°)-ethyl ether mixture; literature[9] m.p. 106°.

LAFAYETTE, IND.

[CONTRIBUTION FROM THE RESEARCH DEPARTMENT, UNION CARBIDE CHEMICALS CO.]

The Reaction of Nitrosyl Chloride with Acetophenone in Ethanol–Pyridine Solution[1]

BY DAVID T. MANNING AND HARRY A. STANSBURY, JR.

RECEIVED NOVEMBER 26, 1958

The reaction between nitrosyl chloride and acetophenone at 25 to 60° in an ethanol medium containing pyridine was studied. Phenylglyoxal aldoxime and benzoic acid were obtained in low yields and the main reaction products were ethyl benzoate, ethyl phenylacetate, ethyl phenylglyoxylate and phenylglyoxal diethyl acetal. By treatment of phenylglyoxal aldoxime with nitrosyl chloride under the conditions of the acetophenone reaction, the oxime was shown to be the intermediate responsible for the formation of all of these products with the exception of ethyl phenylacetate. Simple acid-catalyzed solvolysis of the aldoxime under the mild conditions employed did not occur. Ethyl phenylglyoxylate and phenylglyoxal diethyl acetal were probably formed by reaction of phenylglyoxal aldoxime with nitrosyl chloride to give an intermediate which then decomposed by either of two pathways, one leading to phenylglyoxylyl chloride and the other to phenylglyoxal. Reaction of these with ethanol would yield the observed ester and acetal, respectively. Ethyl phenylacetate was probably formed from α-nitrosoacetophenone by reaction with nitric oxide to give diazoacetophenone which then underwent the Wolff rearrangement.

Introduction

The nitrosation of acetophenone to give phenylglyoxal aldoxime has been accomplished employing either basic or acidic conditions. When the nitrosation was performed with sodium ethoxide and a nitrite ester, a 50% yield of phenylglyoxal aldoxime was obtained,[2–5] whereas the use of nitrite ester and a mineral acid catalyst, in general, has led to inferior results.[5–7] Hartung[5] obtained

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[1] D. T. Manning and H. A. Stansbury, Jr., Abstracts of Papers, 133rd Meeting, American Chemical Society, April 13 to 18, 1958, p. 93-N.

[2] L. Claisen, *Ber.*, **20**, 655 (1887).

[3] L. Claisen and O. Manasse, *ibid.*, **20**, 2194 (1887).

[4] L. Claisen, *ibid.*, **38**, 693 (1905).

[5] W. H. Hartung, J. C. Munch, W. A. Deckert and F. Crossley, THIS JOURNAL, **52**, 3317 (1930).

[6] L. Claisen and O. Manasse, *Ber.*, **22**, 526 (1889).

[7] W. K. Slater, *J. Chem. Soc.*, **117**, 587 (1920).