

Cyanoethylation of Ketostearates¹

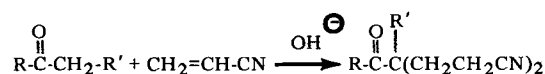
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ABSTRACT

Reaction of methyl 9(10)-ketostearate with acrylonitrile under basic catalysis leads to the formation of new carbon-carbon bonds by the introduction of one to four β -cyanoethyl groups on carbon atoms adjacent to the carbonyl function. Five cyanoethylated products of 4-heptanone have been isolated and identified. A GLC method has been developed to separate and determine four of the cyanoethylated derivatives of methyl 9(10)-ketostearate and methyl 12-ketostearate but the fifth, the tetracyanoethylated product, cannot be determined by this procedure. With the aid of this analytical method a study of some of the reaction parameters was undertaken to determine the degree to which yields and product distribution could be influenced by change in reaction conditions. Among the factors studied were amount of catalyst, reagent ratio, reaction temperature, use of solvents and precision. These series of experiments revealed that the degree of cyanoethylation of methyl 9(10)-ketostearate can be varied within wide limits, but that monocyanoethylation cannot be accomplished in realistic yields without the simultaneous formation of polycyanoethylated products.

INTRODUCTION

The cyanoethylation of simple dialkyl ketones has been studied in some detail (1), but this reaction of acrylonitrile is less well known than those with other types of compounds such as alcohols and amines. Bruson and Reiner demonstrated (2) that ketones having α -hydrogen atoms react with acrylonitrile in the presence of base with the formation of new carbon-carbon bonds:



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Methylene hydrogens were shown to be more active than methyl, and up to four methylene hydrogen atoms were shown to be replaceable. Moreover, in the presence of multiple α -hydrogen atoms monocyanoethylation required the use of special conditions (3,4). Some selectivity of substitution at methine carbon over methylene was also found (5), but the evidence for this was not very strong, and was clouded by highly influential steric factors.

Cyanoethylation is known to be reversible (6), and decyanoethylation occurs with some ease when the β -cyanoethyl group is attached to oxygen, nitrogen or sulfur. In our earlier work concerning the cyanoethylation of fatty hydroxy derivatives (7), we were successful in obtaining the required β -cyanoethyl ethers in excellent yield. These products, however, proved to be fairly unstable, in acid medium because of an acid-catalyzed elimination reaction, and in basic medium because of decyanoethylation (8).

The purpose of the present work was to investigate the cyanoethylation of fatty ketones, thereby attaching the β -cyanoethyl group directly to the aliphatic carbon skeleton by new carbon-carbon bonds rather than through an ether linkage. It was anticipated that new and more stable polyfunctional derivatives of fatty acids could be prepared. Preliminary cyanoethylations were performed with 4-heptanone as a model compound. The latter ketone was chosen because its symmetrical structure minimizes the number of isomeric products to be expected and its relatively low molecular weight facilitates analysis of product mixtures by gas liquid chromatography (GLC). Synthetic and analytical experience gained with the model ketone was then applied to the increasingly complex problems of the cyanoethylation of methyl 9(10)-ketostearate. The mixed 9- and 10-ketostearate products gave very complex mass spectral data. For this reason methyl 12-ketostearate was cyanoethylated to take advantage of the more simple fragmentation patterns of its derivatives.

EXPERIMENTAL PROCEDURES

Materials Used

4-Heptanone. Practical grade (Eastman) was distilled, and

TABLE I

Elemental Analysis of Cyanoethylated Ketones

No. of cyanoethyl groups		Theory C	Found C	Theory H	Found H	Theory N	Found N
Methyl 9(10)-ketostearate							
1	C ₂₂ H ₃₉ O ₃ N	72.28	72.36	10.75	10.92	3.83	3.98
2(sym)	C ₂₅ H ₄₂ O ₃ N ₂	71.75	71.84	10.11	10.09	6.69	6.22
2(unsym)	C ₂₅ H ₄₂ O ₃ N ₂	71.75	71.75	10.11	10.42	6.69	6.29
3	C ₂₈ H ₄₅ O ₃ N ₃	71.30	71.15	9.62	9.67	8.91	8.77
Methyl 12-ketostearate							
1	C ₂₂ H ₃₉ O ₃ N	72.28	72.16	10.75	10.76	3.83	3.78
2	C ₂₅ H ₄₂ O ₃ N ₂	71.73	71.44	10.11	10.35	6.69	6.68
3	C ₂₈ H ₄₅ O ₃ N ₃	71.30	71.21	9.62	9.84	8.91	9.17
4	C ₃₁ H ₄₈ O ₃ N ₄	70.95	71.04	9.22	9.59	10.68	10.38
4-Heptanone							
1	C ₁₀ H ₁₇ ON	71.81	72.15	10.25	10.43	8.38	8.08
2	C ₁₃ H ₂₀ ON ₂	70.87	70.81	9.15	9.08	12.72	12.74
3	C ₁₆ H ₂₃ ON ₃	70.29	70.05	8.48	8.37	15.37	15.35
4	C ₁₉ H ₂₆ ON ₄	69.90	69.73	8.03	7.57	17.16	17.54

TABLE II

Reproducibility of Cyanoethylation of Methyl 9(10)-Ketostearate. Product Composition ^a (Wt%)					
Induction period, sec	Unreacted	No. of cyanoethyl groups			
		1	2(Sym)	2(Unsym)	3
130	33.9	24.3	13.6	6.4	21.8
130	34.1	23.9	13.5	7.3	21.3
125	33.2	23.4	13.4	8.0	22.0

^aStarting mixture: 1.0 g (0.0032 moles) methyl 9(10)-ketostearate, 13.4 g (0.253 moles) acrylonitrile, 1.4 ml (0.0032 moles) BTAH solution.

the fraction boiling at 143.5 C (lit. 144 C), purity 97% by GLC, was used.

Methyl 9(10)-Ketostearate. Oleic acid, commercial grade, purity 90% by GLC, was converted to 9(10)-hydroxystearic acid by the method of Knight et al. (9,10). The secondary alcohol was oxidized to the ketone with chromic acid (11), and the product was esterified and purified to give methyl 9(10)-ketostearate. Purity 97+% by GLC.

Methyl 12-Ketostearate. Commercial grade 12-hydroxystearic acid was oxidized with chromic acid (11), esterified and purified to give methyl 12-ketostearate, purity 97+% by GLC.

Acrylonitrile. Practical grade acrylonitrile (Eastman) was distilled through a Vigreux column, and the fraction boiling at 77 C (purity, 98+% by GLC) was used. Water (0.5% by weight) was added to the distilled product as a stabilizer.

Benzyltrimethylammonium Hydroxide (BTAH). A 38.5% aqueous solution (Eastern Chemical Corp.) was used as received.

Analytical Procedures

GLC of the starting materials methyl 9(10)-ketostearate, methyl 12-ketostearate and 4-heptanone was carried out with 8 ft x 1/4 in. stainless steel columns packed with 10% diethylene glycol succinate on 60-80 mesh Gas Chrom Q. The higher boiling cyanoethylated compounds were analyzed on 16 x 1/4 in. stainless steel columns packed with 4% OV-17 on 60-80 mesh Gas Chrom Q. The higher boiling cyanoethylated compounds were analyzed on 16 x 1/4 in. stainless steel columns packed with 4% OV-17 on 60-80 mesh Chromosorb AW-DMCS. These columns were aged for two days at 350 C and then further treated by injecting 200 μ l of crude cyanoethylation reaction mixtures, raising the temperature to 400 C and holding it there for 2 hr. A large amount of the liquid phase was removed by this treatment, but it allowed the columns to be programmed to 350 C without baseline drift due to excessive bleeding. The treatment with the crude reaction mixtures improved the separation of positional isomers of dicyanoethylated methyl 9(10)-ketostearate. The helium gas flow was maintained at 60 ml/min for all columns. Components represent-

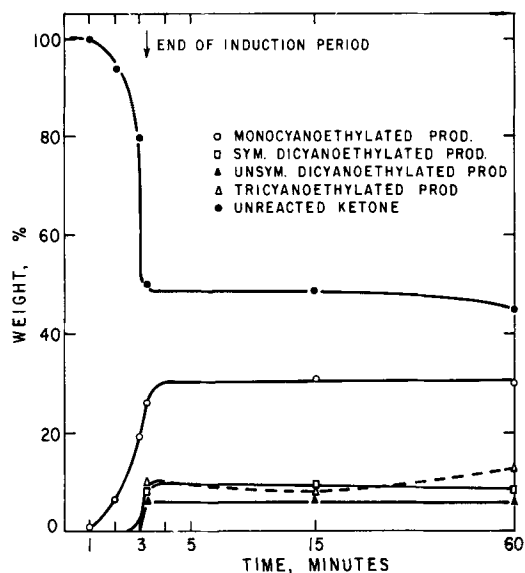


FIG. 1. Product composition vs. time during cyanoethylation of 4-heptanone.

ing peaks were trapped and identified by IR mass spectral and elemental analyses.

Analytical and preparatory TLC plates were coated with silica gel containing 10% binder (Adsorbasil 2) and were activated by heating at 110 C for 2 hr. Analytical plates were charred after being sprayed with a solution of potassium dichromate in aqueous sulfuric acid. Preparatory plates, after development, were sprayed with an alcoholic solution of 2',7'-dichlorofluorescein, and the bands were located under UV light. Components representing these bands were extracted and identified. Preparatory TLC was used to check the accuracy of the quantitative GLC data. IR spectra were determined with a Perkin-Elmer Model 257 spectrophotometer. Mass spectra of cyanoethylated ketostearates were determined on a CEC 103 C or a CEC 110 mass spectrometer. Elemental analyses were carried out on an F&M Model 185 C, H, N Analyzer. GLC analyses were carried out on an F&M model 810 gas chromatograph.

Cyanoethylation of Methyl 9(10)Ketostearate

A solution of methyl 9(10)-ketostearate (1.0 g, 0.0032 mole) in 13.5 g (0.25 mole) of acrylonitrile was placed in a 1 liter 2 neck round-bottom flask, which was equipped with a magnetic stirrer, kept at the same speed for all experiments, and with a reflux condenser. The temperature of the reaction mixture prior to the addition of base was kept at 27 ± 1 C. To the mixture was added rapidly 1.4 ml of BTAH solution containing 0.0032 moles of catalyst. After an induction period of 130 sec an almost instantaneous darkening of the solution was accompanied by heat generation, causing the mixture to reflux. In duplicate experiments the induction period was reproduced within

TABLE III

Cyanoethylation of Methyl 9(10)-Ketostearate
Effect of Variation in Reaction Temperatures

Temperature C	Induction period, sec	Product composition, (Wt%)				
		Unreacted	No. of cyanoethyl groups			
			1	2(Sym)	2(Unsym)	3
5	9780 ^a	24	17.2	21.1	3.4	34.3
15	840	40.7	25.0	17.8	5.5	21.0
26	130	33.9	24.3	13.6	6.4	21.8
40	18	35.9	24.9	13.9	8.2	17.1
60	3	40.7	24.5	12.3	8.3	14.2
80	0 ^b	39.9	26.4	12.9	9.6	11.3

^aOne hour stirring after exotherm.

^bExotherm occurs before all catalyst was added.

TABLE IV
Cyanoethylation of Methyl 9(10)-Ketostearate. Effect of Dilution With Cosolvent

Cosolvent	Dilution ratio ^a	Induction period, sec	Product composition, (Wt%)				
			Unreacted	No. of cyanoethyl groups			
				1	2(Sym)	2(Unsym)	3
None	---	130	33.9	24.3	13.6	6.4	21.8
Pyridine	2:1	10	44.8	24.7	10.8	5.5	14.3
Pyridine	1:1	3	65.6	19.6	8.7	1.8	4.2
Pyridine	1:2	1	86.6	12.7	2.9	tr	0.8
DMSO ^b	2:1	0	65.4	22.8	8.4	0.2	0.1
HMPA ^c	2:1	0	71.2	21.3	5.9	1.2	0.5

^aAcrylonitrile cosolvent (v/v).

^bDimethylsulfoxide.

^cHexamethylphosphoric triamide.

± 5 sec. After 1 hr of stirring the mixture was diluted with 20 ml of water and 15 ml of acetone. The mixture was then neutralized with diluted HCl and extracted with three 50 ml portions of ether. The combined ether extracts were washed with water, dried over anhydrous sodium sulfate, and concentrated to give 3.4 g of a yellow semisolid. IR indicated that polymer and a small amount of free acid were present in the product. The latter was methylated with a 20% boron trifluoride in methanol solution to give 2.3 g of light yellow semisolid. The IR spectrum (neat) showed polymer (2225 cm⁻¹) to be still present as impurity.

GLC analysis demonstrated the following product composition: methyl 9(10)-ketostearate, 33.7%; monocyanoethylated ketostearate, 23.9%; "symmetrical" dicyanoethylated ketostearate, 13.5%; "unsymmetrical" dicyanoethylated ketostearate, 7.2%; tricyanoethylated ketostearate, 21.7%. [References to symmetry are used to describe the disposition of β-cyanoethyl groups relative to the carbonyl function.] Analysis by TLC indicated that there was less than 3% of tetracyanoethylated ketostearate in the mixture. Pure samples of the products, except the tetracyanoethylated material, were isolated by preparative GLC. Results of their elemental analyses (Table I) were compatible with the proposed structures.

Cyanoethylation of Methyl 12-Ketostearate

The reaction was performed as described above for methyl 9(10)-ketostearate. Analysis of the reaction products showed that yields and compositions were similar to those obtained by the cyanoethylation of the 9(10)-ketostearate. Pure components for elemental analysis were obtained by preparative TLC and are shown in Table I. The dicyanoethylated ketones were not separated on the TLC plate, but these components were later separated by preparative GLC. The mass spectra of the mono-, di-(sym), di-(unsym) and tricyanoethyl derivatives showed parent peaks at (m/e 365), (m/e 418), (m/3 418) and (m/e 471)

respectively. The fragmentation patterns also agree with the predicted structures. Characteristic large peaks due to the rupture of the carbon chain on either side of the carbonyl group were found in all spectra. From these data it appears that the dicyano ethyl derivative having the shortest GLC retention time is the symmetrical isomer. Mass spectral data also reveal that the predominating tricyanoethyl isomer is the one in which the hydrogens on the 11 carbon are fully substituted.

Cyanoethylation of 4-Heptanone

To a mixture of 4-heptanone (8.17 g, 0.0716 moles) in 15.2 g (0.286 mole) acrylonitrile was added 1.6 ml of BTAH solution (.0037 moles) under conditions described for the cyanoethylation of methyl 9(10)-ketostearate above. Special care was taken to avoid loss of 4-heptanone during the vigorous exotherm which occurred at 90 sec. The sample was stirred for 1 hr and was worked up as described above. GLC analysis showed 44.5% unreacted 4-heptanone, 30.0% monocyanoethylated ketone, 7.9% of symmetrical and 5.4% of unsymmetrical dicyanoethylated ketone and 12.2% tricyanoethylated derivative. The individual products were isolated by preparative GLC, and their elemental composition was determined (Table I).

Reproducibility of Cyanoethylation Results

The cyanoethylation of methyl 9(10)-ketostearate was repeated several times to determine precision. Results are shown in Table II.

Variation of Reaction Parameters

The cyanoethylation of methyl 9(10)-ketostearate was carried out as described above, but individual variables of the reaction were adjusted to evaluate their effect on product yield and composition. Isolation procedures and analytical techniques remained essentially unaltered.

Reaction Temperature. The cyanoethylation was carried out at temperatures ranging from 5 C, the approximate

TABLE V
Cyanoethylation of Methyl 9(10)-Ketostearate. Effect of Different Catalysts

Catalyst	Moles	Solvent	Reaction time, hr	Production composition, ^a (Wt%)				
				Unreacted	No. of cyanoethyl groups			
					1	2(Sym)	2(Unsym)	3
BTAH	0.0032	MeOH	1	88.9	9.9	1.2	---	---
BTAH	0.0032	H ₂ O	1	33.7	23.9	13.5	7.2	21.7
NaOH	0.0032	H ₂ O	1	100	---	---	---	---
NaNH ₂	0.0032	---	20	93.8	4.9	1.0	---	0.2
Triethylamine	0.0032	---	20	100	---	---	---	---
Na methoxide	0.0032	---	2	69.1	21.6	9.3	---	---
K t-butoxide	0.0022	---	20	89.9	6.9	1.6	0.4	1.2

^aStarting mixture: 1.0 g (0.0032 moles) methyl 9(10)-ketostearate, 13.45 g (0.253 moles) acrylonitrile.

TABLE VI
 Cyanoethylation of Methyl 9(10)-Ketostearate

Mole ratio	Induction period, sec	Product composition, (Wt%)				
		Unreacted	No. of cyanoethyl groups			
			1	2(Sym)	2(Unsym)	3
Effect of change in ratio of catalyst ^a to methyl 9(10)-ketostearate						
.13	115	74.5	17.8	7.2	---	0.54
.25	60	70.0	19.6	8.6	0.2	1.6
1	130	33.9	24.3	13.6	6.4	21.8
2	150	25.1	23.9	15.4	14.3	21.2
4 ^b	165	19.9	26.2	24.3	5.6	24.0
Effect of change in ratio of acrylonitrile to methyl 9(10)-ketostearate ^c						
160	70	28.1	21.9	12.5	5.8	31.8
80	130	33.9	24.3	13.6	6.4	21.8
40	153	37.6	24.6	12.6	7.9	17.2
20	230	46.5	24.3	10.5	5.7	13.0
10	300	56.4	24.3	8.3	3.7	7.3
5	3600 ^d	99	---	---	---	---

^aBenzyltrimethylammonium hydroxide (BTAH) as 38.5% aqueous solution.

^bLarge amount of polymer and possibly the tetracyanoethyl derivative.

^cStarting mixture: 13.45 g (0.253 moles) acrylonitrile, 1.4 ml (0.0032 moles) BTAH solution.

^dNo exotherm.

solidification point of the mixture, to 80 C, at which temperature the exotherm occurred instantaneously upon catalyst addition. Results are shown in Table III.

Effect of Cosolvents. Solvent was added to the reaction mixture prior to the addition of catalyst, and without change in the amount of acrylonitrile. Dimethylsulfoxide and hexamethylphosphoric triamide cause the addition of catalyst to result in an instantaneous, vigorous exotherm. Results are shown in Table IV.

Variation in Catalysts. Various bases were added to act as substitute catalysts in place of aqueous BTAH. Samples were taken at 1 hr and analyzed. Some reaction solutions underwent slow color changes (yellow, red, violet, brown), these reactions were allowed to stir 20 hr before being worked up. Results are listed in Table V.

Amount of Catalyst. Effects of varying catalyst concentrations are shown in Table VI. At high catalyst levels GLC analysis was complicated by the presence of larger than usual amounts of ether-soluble acrylonitrile polymers. At the highest levels significant amounts of tetracyanoethylated ketostearate became evident during TLC analyses.

Water as Moderator. Small amounts of water were added to the reaction mixture, prior to catalyst addition, to moderate the vigor of the reaction. Results are listed in Table VII.

Concentration of Ketone. The molar ratio of acrylonitrile to ketostearate was varied to give the data shown in Table VI. The molar ratio of 5 approximates the solubility

limit of the ketone in acrylonitrile at 26 C.

RESULTS AND DISCUSSION

The cyanoethylation of hydroxy derivatives of fats was studied previously at our laboratory (7). This work revealed that (a) long chain alcohols cannot be cyanoethylated in acceptable yields by use of standard procedures; (b) these compounds can be cyanoethylated in high yields when excess acrylonitrile is the solvent; (c) cyanoethylation in acrylonitrile solvent with the help of a strong base catalyst competes with the base-induced polymerization of acrylonitrile, but cyanoethylation is nearly complete at the end of the polymerization induction period.

The present investigation disclosed that the requirements for the cyanoethylation of long chain aliphatic ketones approximate those of the corresponding alcohols quite closely. Not unexpectedly, however, the reaction of the ketones occurs less readily, and the product composition is more complicated than that of the alcohols. The decrease in reactivity is undoubtedly caused by the lower acidity, and hence the greater difficulty of abstraction by base, of the α -hydrogens compared with the hydroxylic protons. As a result, less ketone than alcohol is converted to cyanoethylated products before onset of polymerization, but the unreacted ketostearate is readily recovered from the product mixture by a simple extraction with hexane.

The presence of four hydrogens on α -methylene groups of the unsymmetrical fat-derived ketones permits formation

 TABLE VII
 Cyanoethylation of Methyl 9(10)-Ketostearate
 Effect of Addition of Water as Moderator

Total H ₂ O present, %	Induction period, min	Product composition ^a , (Wt%)				
		Unreacted	No. of cyanoethyl groups			
			1	2(Sym)	2(Unsym)	3
5.6	2	33.9	24.3	13.6	6.4	21.8
7.1	4	30.5	22.3	13.9	12.3	20.9
9.1	14	33.6	24.6	13.6	10.4	17.8
11.1	33	30.1	24.3	15.7	13.7	16.2
13.1	70	33.5	27.0	16.2	13.7	12.6

^aStarting mixture: 1.0 g (0.0032 moles) methyl 9(10)-ketostearate, 13.4 g (0.253 moles) acrylonitrile, 1.4 ml (0.00323 moles) BTAH solution.

of eight different cyanoethylation products. Complexity of the product mixtures therefore makes the isolation and identification of individual components difficult. Initial exploratory studies were carried out on 4-heptanone, because the symmetry of this ketone decreases the number of positional isomers, and because the relative volatility of the products decreases interference from low-molecular weight acrylonitrile polymers during GLC analysis. Four cyanoethylation products, including a mixture of the symmetrical and the unsymmetrical disubstituted products, were isolated by preparatory GLC, subjected to elemental analysis (Table I) and identified by mass spectrometry.

The cyanoethylation products of methyl ketostearates were subjected to analytical and preparative GLC and TLC, and the components were isolated and subjected to IR, elemental and mass spectral analyses. The disubstituted 12-ketone was separated into two types of isomers, the 11,13-di(2-cyanoethyl)-12-ketostearate, the symmetrical isomer, and a mixture of the 11,11- and 13,13-di(2-cyanoethyl)-12-ketostearate, the unsymmetrical isomer. Other positionally isomeric pairs could not be resolved by either GLC or TLC, but their presence was indicated by mass spectrometry.

Reaction of methyl 9(10)-ketostearate with acrylonitrile gave product mixtures which were entirely analogous in yield and composition to those obtained from 12-ketostearate. Again, the only isomeric products which were separable were the symmetrical and the unsymmetrical disubstituted products. None of the tetracyanoethylated ketostearates were detectable by GLC up to 400°C and therefore these had to be isolated and identified from preparative thin-layer chromatograms only. The total amount of this isomer was usually 3% or less of the product mixture.

Both GLC and TLC techniques were necessary in the identification of individual compounds, since the presence of numerous low molecular weight acrylonitrile polymers made peak assignments uncertain. These polymers remain with the cyanoethylation products during the work-up procedures because of their solubility in ether. The amounts of these extraneous materials varied with reaction conditions. Higher molecular weight polymers were insoluble in ether and were removed by filtration.

The various adducts can be readily distinguished by IR analysis of their pure forms, and the degree of cyanoethylation in the crude reaction mixtures also can be estimated closely. The intensity of the 2250 cm^{-1} ($\text{C}\equiv\text{N}$) band varied quantitatively as the number of nitrile groups per molecule. The ketone band located at 1705 cm^{-1} ($>\text{C}=\text{O}$) in the spectrum of mono- and symmetrical dicyanoethylated ketones shifts to 1701 cm^{-1} in the unsymmetrical disubstituted ketones and to 1690 cm^{-1} in the tri- and tetrasubstituted derivatives. The ether soluble polymers which are present in most crude reaction extracts show a strong 2250 cm^{-1} peak with a minor peak at 2225 cm^{-1} in their IR spectra.

Before the effects caused by variation of reaction parameters could be assessed, it was necessary to determine the precision of the cyanoethylation reaction and its analytical procedures. It is apparent from Table II that the induction period, conversion and product composition are quite reproducible.

Variations in the reaction temperature did not greatly affect the degree of cyanoethylation of ketostearates (Table III), although a large temperature effect was noted in the analogous reaction of hydroxystearates (7). Minor differences in the relative amounts of polycyanoethylated ketones were observed, especially an apparent decrease of trisubstituted and unsymmetrically disubstituted products with increase in temperature. At 5°C no distinct onset of rapid polymerization was observed, and the reaction period was rather arbitrarily set at about 2-3/4 hr. At this low

temperature, the amount of tetracyanoethylated product was unusually large (estimate ~ 15%).

Use of other solvents in conjunction with acrylonitrile decreased the amount of ketone which reacted (Table III), and especially decreased the amount of polysubstituted product formed. Cosolvents also decreased the degree of cyanoethylation of hydroxystearate. The diluent appeared to favor polymerization of acrylonitrile. Extreme caution must be used when the cyanoethylation is carried out in the presence of hexamethylphosphoric triamide (HMPA) and dimethyl sulfoxide (DMSO). Both of these solvents, and probably others, cause an almost instantaneous violent reaction when the catalyst is added. The rapid polymerization can be delayed, but not avoided, by the addition of hydroquinone as inhibitor.

Other catalysts were used to promote the cyanoethylation of ketones (Table V), but none tested approached aqueous benzyltrimethylammonium hydroxide (BTAH) in efficiency.

Variations in the amount of BTAH affect the degree of cyanoethylation, as expected (Table VI). The yield of monocyanoethyl derivatives was only slightly changed over the catalyst concentration range studied, but the total yield of cyanoethylated products was directly related to the amount of catalyst used. The polycyanoethyl adducts showed the greatest dependency on catalyst concentration. Unfortunately, use of high catalyst levels increased the amount of ether soluble polymers formed as well as the polycyanoethyl adducts. As a result, products were difficult to purify and to analyze by GLC. Substantial changes in catalyst amounts caused relatively minor variations in the induction period. The constancy in the latter is undoubtedly the result of a balance between a rate-increasing effect of higher catalyst levels and the rate-retarding effect of the increased amount of water added simultaneously. This inhibiting effect of water was observed previously and was again noted here (Table VII). The total conversion of ketostearate, and the formation of monocyanoethylation adduct did not change as the reaction was slowed, but the amount of tricyanoethylated product was steadily reduced with simultaneous relative increase of the disubstitution product, especially the unsymmetrical isomer.

Decreases in the excess acrylonitrile present, i.e., reduction of the acrylonitrile-ketone mole ratio (Table VI), resulted in decreased degrees of cyanoethylation and, of course, in lessened polycyanoethylation. However, suitable conditions for preventing polysubstitution entirely were not encountered. An interesting feature of this series of reactions is the fairly constant yield of the monosubstituted derivative regardless of the amount of acrylonitrile available. While the foregoing work clearly indicates the effect of reaction parameters on product yields and compositions, the reasons for these results are much less clear. Under our standard conditions (Table II) the molar ratios of mono-di-tri-cyanoethylation products approximates 1.5:1.1:1.0. Furthermore, the symmetrical disubstituted product is always found in much higher concentration than the unsymmetrical product. The remarkably large amounts of polycyanoethylation products found seem to indicate that cyanoethylated products react more rapidly with acrylonitrile than the unsubstituted ketone. Although relative ease of abstraction of secondary versus tertiary hydrogen atoms and steric inhibition probably each play a role in determining the product ratio, this role does not seem to be important except, perhaps, in causing the preponderance of symmetrical over unsymmetrical disubstitution product. On the other hand, the ready formation of polycyanoethylated products can be rationalized on the basis of the concept that the presence of one or more cyanoethyl groups in the molecule facilitates solvation of the enolate anion. This interpretation of the experimental results requires confirmation by future work.

ACKNOWLEDGMENTS

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