2 H), AB quartet centered at 6.22 (J = 11.5 Hz, 4 H), 6.53 ppm (s, 2 H); ^{13}C NMR shows 14 signals; IR 1685, 1600, 1550 cm^{-1}; UV-vis 346 nm (log ϵ 2.85), shoulder at 280 (3.4), 221 (4.35); mass spectrum (EI), molecular ion at m/e 480.

Anal. Calcd for $C_{28}H_{32}O_7$: C, 69.98; H, 6.71. Found: C, 69.93; H, 6.85.

Reduced Hexaketone 7a. The procedure is as for **5a** above with 165 mg (0.344 mmol) of tri-ring-opened **7**, 10 mg of 10% Pd on carbon, and 20 mL of EtOAc. After evaporation of the solvent in vacuo, the colorless oil is crystallized by cooling in hexane–benzene (3:1) at −10 °C for 24 h, giving 117 mg of **7a** (70%) as very small white prisms: mp 143–144 °C; ^1H NMR 1.33 (s, 12 H), 1.38 (s, 12 H), 2.48 (s, 8 H), 2.55 (s, 4 H), 5.97 ppm (s, 2 H); IR 1700, 1540 cm^{-1}; mass spectrum, (EI), molecular ion at m/e 486.

Anal. Calcd for $C_{28}H_{38}O_7$: C, 69.11; H, 7.87. Found: C, 68.78; H, 8.02.

Di-Ring-Opened *cis*-Enediones 8 and 9. To a magnetically stirred 100-mL round-bottomed flask containing 0.70 g (1.6 mmol) of tetramer **1** dissolved in 45 mL of $CHCl_3$ at 0 °C is added 0.73 g (2.2 equiv) of MCPBA. The reaction mixture is stirred at 0 °C for 1 h and at 20 °C for an additional 2 h. After a workup in the usual manner, the solvent is removed in vacuo and the solids are broken up in 10 mL of ice-cold EtOH. Suction filtration affords 0.64 g of a mixture which, by TLC analysis (SiO_2; $CHCl_3$–EtOAc, 8:1), shows three major components, R_f 0.62, 0.52, and 0.37. Flash chromatography enables separation of this mixture (45-mm-diameter column, 150 g of 230–400-mesh silica gel, elution with 9:1 $CHCl_3$–EtOAc, flow rate of 75 mL/min), giving 0.24 g of **8** (32%; elutes first), 0.26 g of **9** (36%; elutes second), and 0.15 g of tri-ring-opened **7** (19%; elutes last). The di-ring-opened *cis*-enediones **8** and **9** can each be recrystallized from $CHCl_3$–EtOH (1:6), giving 0.19 g of **8** as tiny pale yellow prisms (mp 211–212 °C) and 0.20 g of **9** as pale greenish yellow plates, mp 165–166 °C.

Spectra for **8** include: ^1H NMR 1.45 (s, 24 H), 5.97 (s, 4 H), 6.00 ppm (s, 4 H); ^{13}C NMR 23.08, 48.19, 106.95, 134.13, 156.88, 202.26 ppm; IR 1700, 1611, 1600, 1550 cm^{-1}; UV-vis shoulder at 333 nm (log ϵ 3.0), 227 (3.53), 221 (4.41); mass spectrum (EI), molecular ion at m/e 464.

Anal. Calcd for $C_{28}H_{32}O_6$: C, 72.39; H, 6.94. Found: C, 72.29; H, 6.98.

Spectra for **9** include: ^1H NMR 1.18 (s, 6 H), 1.52 (s, 12 H), 1.58 (s, 6 H), AB q centered at 5.87 (J = 3.1 Hz, 4 H), AB q centered at 5.95 ppm (J = 12 Hz, 4 H); IR 1698, 1681, 1603, 1540 cm^{-1}; UV-vis shoulder at 332 nm (log ϵ 2.8), shoulder at 290 (3.1), 221 (4.32); mass spectrum (EI), molecular ion peak at m/e 464.

Anal. Calcd for $C_{28}H_{32}O_6$: C, 72.39; H, 6.94. Found: C, 72.50; H, 7.04.

Di-Ring-Opened *trans*-Enediones 3 and 10. To a magnetically stirred 250-mL round-bottomed flask containing 2.00 g (4.63 mmol) of tetramer **1** dissolved in 150 mL of $CHCl_3$ at 20 °C is added 1.88 g (2.0 equiv) of MCPBA. After the mixture was stirred at 20 °C for 45 min, 25 drops of concentrated HCl are added, causing a deepening of the initially pale yellow solution, and the acidified mixture is stirred for an additional 2 h. After the usual workup, the volume is reduced to 20 mL in vacuo. An equal volume of EtOH is added, causing precipitation of **3**. The suspension is cooled to 0 °C for several hours and suction filtered, giving 0.88 g of **3** (41%), identified by its ^1H NMR spectrum. The orange-yellow filtrate is then taken to dryness in vacuo, leaving an oil which, after being allowed to stand in 25 mL EtOH at −10 °C overnight, gives a second crop of crystals. Suction filtration affords 0.41 g of **10** (19%) as yellow-orange prisms: mp 159–160 °C; ^1H NMR 1.33 (s, 6 H), 1.40 (s, 12 H), 1.52 (s, 6 H), AB q centered at 6.00 (J = 3.2 Hz, 4 H), AB q centered at 6.72 ppm (J = 16 Hz, 4 H); ^{13}C NMR shows 14 signals; IR 1700, 1680, 1615, 1600, 1548 cm^{-1}; UV-vis 382 nm (log ϵ 3.03), 306 (3.38), 233 (4.47); mass spectrum (EI), molecular ion at m/e 464.

Anal. Calcd for $C_{28}H_{32}O_6$: C, 72.39; H, 6.94. Found: C, 72.22; H, 6.91.

Reduced Tetraketone 9a. The procedure is as for **5a** above and with either **9** or **10** gives **9a**. Reduction of 150 mg (0.323 mmol) of the *trans*-enedione **10** in 25 mL of EtOAc with 10 mg of 10% Pd on carbon produces 111 mg of **9a** (74%) from EtOH as white needles: mp 162–163 °C; ^1H NMR 1.27 (s, 6 H), 1.40 (s, 12 H), 1.52 (s, 6 H), 2.45 (m, 8 H), 5.88 ppm (s, 4 H); IR 1695, 1550 cm^{-1} mass spectrum (EI), molecular ion at m/e 468.

Anal. Calcd for $C_{28}H_{36}O_6$: C, 71.77; H, 7.74. Found: C, 71.32; H, 7.79.

***cis*-3-Hexene-2,5-dione.**[11a] To a magnetically stirred 100-mL round-bottomed flask containing 1.00 g (10.4 mmol) of freshly distilled 2,5-dimethylfuran in 55 mL of CH_2Cl_2 at −10 °C is added 2.33 g (1.1 equiv) MCPBA in one portion. Stirring is continued overnight, allowing the cooling bath to warm to 20 °C. The milky white suspension is worked up as usual, and removal of the solvent in vacuo leaves 1.16 g (99%) of *cis*-3-hexene-2,5-dione as a very pale yellow liquid: ^1H NMR 2.18 (s, 6 H), 6.18 ppm (s, 2H); ^{13}C NMR 29.27, 135.32, 200.11 ppm; IR (neat) 1698, 1616 cm^{-1}. This substance isomerizes to the crystalline *trans*-enedione[11a] upon being allowed to stand under N_2 at 0 °C over a period of several weeks.

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Registry No. 1, 22900-44-3; 2, 61093-57-0; 3, 78804-49-6; **3a**, 78804-50-9; 4, 78804-51-0; 5, 78804-52-1; **5a**, 78804-53-2; 6, 78804-54-3; **6a**, 78804-55-4; 7, 78804-56-5; **7a**, 78804-57-6; 8, 78804-58-7; 9, 78804-59-8; **9a**, 78804-60-1; 10, 78804-61-2; 2,5-dimethylfuran, 625-86-5; *cis*-3-hexene-2,5-dione, 17559-81-8; *trans*-3-hexene-2,5-dione, 820-69-9.

Novel Synthesis of α-Substituted Acrylic Acids[1]

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A facile three-step procedure has been developed for the synthesis of α-substituted acrylic acids. In the first step, a carboxylic acid having no α-substituents is condensed with 2-amino-2-methylpropanol (AMP) to form the corresponding oxazoline. The oxazoline reacts readily with paraformaldehyde to give an intermediate mixture of mono- and dimethylol derivatives which upon heating forms the α-methylene derivatives of the oxazoline. The latter, upon acid hydrolysis, yields the α-substituted acrylic acid generally in an overall yield of above 70% and the acids are usually at least 95% pure.

Introduction

α-Substituted acrylic acids are useful intermediates for the preparation of biologically active materials, lubricant additives, or polymers. Relatively few methods for the synthesis of these acids have been developed, and none of those published have practicality because of awkwardness of some reaction steps, poor yields, use of expensive, toxic or otherwise hazardous reactants or solvents, or extremes

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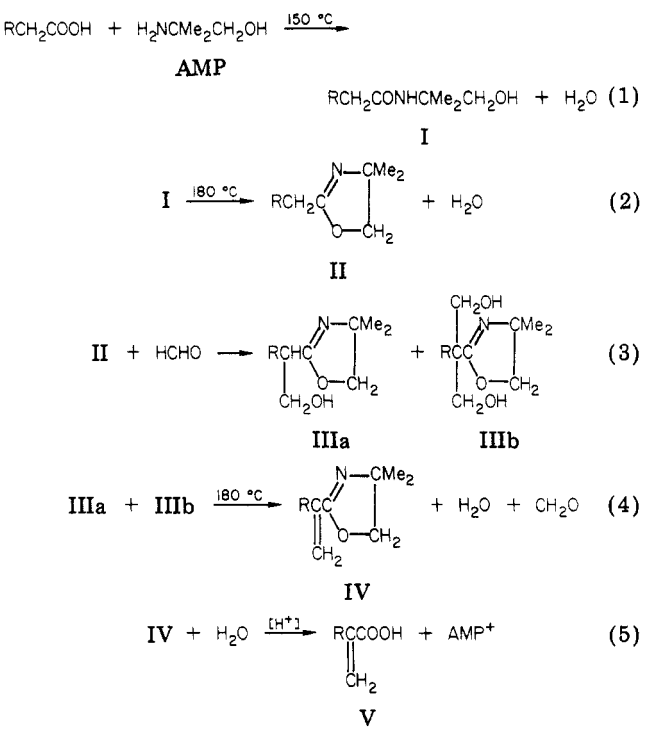
of reaction conditions. Very low or high reaction temperatures or extremely exothermic reactions make it impossible to scale up the synthesis beyond about 10-g batches. The method of Allen and Kahn[3] involves alkylation of diethyl methylmalonate, hydrolysis and decarboxylation, bromination of the resulting α-alkyl propionic acid, and dehydrohalogenation to give an overall yield of 30% of the desired acrylic acid. Chikanishi and Tsuruta[4] alkylated diethyl malonates, hydrolyzed one of the ester groups, and treated the resulting ethyl hydrogen alkylmalonate with formaldehyde while simultaneously decarboxylating the half-ester. Yields of 20–60% are claimed. This methodology was extended by Gisser and Mertwoy[5] to produce derivatives of higher molecular weight in yields of about 35%. Pikh et al.[6] condensed lower molecular weight α-alkyl acroleins with formaldehyde via the Knoevenagel reaction and converted the resulting α-methylene derivatives with pressurized oxygen into the peroxy acids, which were decomposed to the α-alkyl acrylic acids, and overall yields of 57–69% are claimed.

Another approach was developed by Pfeffer and Silbert[7] whereby the α-proton of a fatty acid was abstracted with *n*-butyllithium at −70 °C in the presence of diisopropylamine and a solvent mixture of tetrahydrofuran and hexamethylphosphoramide. The resulting dianion was reacted with gaseous formaldehyde to give the α-alkyl hydracrylic acid, which was dehydrated by heating and distillation in the presence of phosphoric acid, affording the acrylic acid in high yield. Their synthesis could not be scaled up. Ponticello[8] prepared the α-anion of 5-(carboxymethyl)-2-norbornene with the aid of *n*-butyllithium. Treatment with an alkyl halide gave the α-alkyl derivative, which upon pyrolysis at 625 °C yielded the desired α-alkyl acrylic acid in a 50% yield.

In this study a carboxylic acid is converted to the corresponding oxazoline by reaction with 2-amino-2-methylpropanol (AMP); after treatment of the oxazoline with paraformaldehyde, followed by dehydration, acid hydrolysis yields the α-alkyl acrylic acid according to Scheme I.

The synthetic route developed in this study was carried through three reaction steps in one vessel, and the product needed to be removed from the vessel only for purification. The carboxylic acid function of the starting acid was masked by conversion to oxazoline II as described by Wehrmeister[9] and Meyers and Temple.[10] However, in contrast to the methodology developed by these authors, our yields and purity of II were substantially higher and afforded with ease. Conversion to the methylol derivatives IIIa and IIIb has also been described by Wehrmeister; however, the azeotropic dehydration of the crude mixture of IIIa and IIIb to form IV has not been described heretofore. Conversion of IV to the desired acrylic acid V by the procedure of Meyers and Temple[10] was not applicable to oxazolines derived from higher molecular weight acids. The acid hydrolysis method was developed by us especially

Scheme I



for the higher molecular weight fatty acids and appears to be a general one. It achieves essentially complete hydrolysis without formation of byproducts. The compounds synthesized were characterized by their IR and/or UV spectrum.

Results and Discussion

Formation of Oxazoline II. Either an acid or its methyl ester can be used equally advantageously as a starting material for the synthesis. The formation of the oxazoline II proceeds through the intermediate amide I, $RCH_2CONHCMe_2CH_2OH$, which is the chief product, if the reaction between AMP and acid (or methyl ester) is carried out at or below 150 °C. Cyclization of the amide to the oxazoline II is readily accomplished at 165 °C by the application of moderate vacuum (25 mmHg) or by heating to 180 °C at atmospheric pressure. We found it expedient not to isolate the amide but to go directly to the oxazoline II as described below.

The synthesis of I and subsequently II is always accompanied by the formation of the ester amide $RCH_2CONHCMe_2CH_2OOCCH_2R$, an undesirable byproduct. The extent of ester amide formation depends upon the amount of AMP used in the reaction. A stoichiometric amount of AMP gives rise to about 35% of ester amide, whereas use of 100% excess AMP reduces the ester amide content to less than 10%.

The oxazoline II can be purified and separated from the ester amide by distillation. The residual ester amide, in turn, can be converted largely to II by the addition of an alkaline catalyst, e.g., sodium methoxide or potassium hydroxide, and subsequent heating. In this procedure, we combined the use of a 100% excess of AMP with the addition of alkali toward the end of the reaction to neutralize all residual organic acid, affording a finished product whose IR spectrum had essentially no characteristic ester absorption at 1740 cm^{-1} but had the characteristic C=N absorption at 1660 cm^{-1}. The reaction product can be used without any further purification and the yields are essentially quantitative. It should also be noted here that the slight alkalinity of the crude II due to neutralization of free

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organic acid is helpful in conducting the subsequently discussed reaction of II with paraformaldehyde.

Formation of Oxazoline IV. While the conversion of II to IV is essentially carried out in one operation as indicated in Scheme I, the reaction proceeds in two steps and is accompanied by several side reactions. The principal product obtained from the reaction between II and paraformaldehyde is a mixture of the monomethylol derivative IIIa and the dimethylol derivative IIIb. For reasons not well understood, some unreacted II is always present in the reaction mixture regardless of how much excess paraformaldehyde is used. The course of the reaction can be followed readily by GLC and IR spectroscopy.

One of the sources of undesirable byproducts is the Cannizzaro reaction, by which some of the paraformaldehyde is converted to formic acid. The latter, in turn, converts some IIIa and IIIb into formates. The appearance of the characteristic formate absorption in the IR spectrum at 1720 cm^{-1} is an index of the extent of formate byproducts. Neutralization of the free organic acid, as described in the previous section, reduces this side reaction.

Other undesirable byproducts arise from the hydrolysis of the oxazoline ring of II. Oxazoline rings are fairly stable in alkaline medium but tend to hydrolyze under acidic conditions. Thus, the formic acid generated from the Cannizzaro reaction enhances oxazoline ring opening. The water for hydrolysis comes partly from the paraformaldehyde, which contains about 5% moisture, and from the dehydration of the methylol derivatives, which occurs above 120 °C. The oxazoline ring hydrolyzes through rupture of the C=N bond to yield an ester $RCH_2COOCH_2CMe_2NH_2$, and, as this side reaction occurs, the typical ester carbonyl absorption at 1740 cm^{-1} in the IR spectrum noticeably increases. This ester can transesterify the methylol derivatives IIIa or IIIb upon subsequent heating. The esters of IIIa or IIIb and amides of the above amino ester are a major source of nonvolatile impurities in the crude oxazoline IV. The formation of ester byproducts during the reaction between II and paraformaldehyde are indicated by the increasing intensities of infrared absorption at 1720 and 1740 cm^{-1}. Ester formation is minimized by prior neutralization of free organic acid, as stated above, by reaction at as low a temperature as possible along with rapid removal of water formed.

The subsequent dehydration step involves merely heating to about 180 °C and efficiently removing water to minimize oxazoline hydrolysis. Water removal is expedited either by azeotropic distillation or by application of moderate vacuum of about 25 mmHg (water aspirator). Vacuum dehydration is obviously inapplicable to lower molecular weight oxazolines which would distill under these conditions. The course of dehydration is indicated by GLC, which readily separates II from III, and by increased intensity of absorption of the vinyl group conjugated with C=N at 1600 cm^{-1} of the IR.

A slight increase in the amount of II is usually observed during the dehydration step and is accompanied by a decrease in ester carbonyl absorption at 1740 cm^{-1} of the IR. This is probably due to the rearrangement of byproduct ester to amide followed by dehydration to yield II:

$$RCH_2COOCH_2CMe_2NH_2 \rightarrow RCH_2CONHC(CH_2OH)Me_2 \xrightarrow{\Delta} II$$

The reversible rearrangement of alkanolamide to ester is well documented in the chemical literature.[11]

The crude oxazoline IV obtained after dehydration usually contains 10–25% of II, and the formaldehyde addition and dehydration must be repeated to obtain a product containing less than 5% of II. Purification of the crude IV is carried out most readily by vacuum distillation; however, II and IV are not readily separated by fractionation, as described below, since their boiling points are only about 3 °C apart. Oxazoline IV is characterized by two strong absorption bands in the IR spectrum at 1610 cm^{-1} for the conjugated vinyl group and at 1655 cm^{-1} for the cyclic C=N group. The distillation residue generally amounts to 15–20% of the reaction mixture. The IR spectrum of the residue indicates a high ester content and absence of or low-intensity absorption at 1600 cm^{-1} characteristic of a conjugated vinyl group. The residue consists largely of esters of IIIa and IIIb. If the desired acrylic acid V is to be purified by distillation, the intermediate IV need not be distilled, since upon hydrolysis, the ester impurities yield primarily the corresponding hydracrylic acids in addition to some polymeric material. The hydracrylic acids are converted to the acrylic acids IV via the estolides.

Hydrolysis of IV. This step is carried out most readily with 3–4 N hydrochloric acid and, as a mutual solvent, acetic acid. Oxazolines are stable to alkaline hydrolysis and hydrolyze slowly and incompletely with water alone at 200 °C in a pressure vessel. Acid concentration is critical; hydrolysis is slowed down markedly at either above or below the 3–4 N range. Initially, IV is soluble in the acid because of salt formation; ring cleavage of the C=N bond results in the ester $RCH_2COOCH_2CMe_2NH_2$, whose hydrochloride is also water soluble. However, some cleavage of the C—O bond of the ring also occurs, as evidenced by the appearance of a fairly strong secondary amide absorption at 1520 cm^{-1} of the IR spectrum. Part of this amide $RCH_2CONHCMe_2CH_2OH$ may also have formed as a result of the above-mentioned rearrangement of ester to amide. Cleavage of the ester to the acrylic acid V occurs readily, and, while an equilibrium between ester and acid V and AMP should be anticipated under acidic conditions, IR spectra do not indicate presence of ester.

The amide and the acrylic acid V are water insoluble, and, typically, after 30–45-min reflux the reaction mixture becomes turbid and eventually separates into two layers. Because the amide hydrolyzes very slowly, a mutual solvent, such as isopropyl alcohol or acetic acid, expedites hydrolysis. Acetic acid is the preferred solvent, since isopropyl alcohol gives rise to some isopropyl esters of V. The amide hydrolysis is indicated readily by the disappearance of the 1520 cm^{-1} absorption in the IR. This hydrolysis requires a long reaction time and usually a replacement of the used acid by a fresh charge of dilute acid, as shown in the Experimental Section.

The hydrolysis of a distilled oxazoline IV results in very high yields of V. If crude IV is hydrolyzed, some of the corresponding hydracrylic acid is formed. The latter, upon heating and subsequent distillation, is converted into the estolide, which is the presence of 85% phosphoric acid decomposes to give the desired acrylic acid V, and a small amount of resinous material remains. Otherwise, the hydrolysis step is clean and does not give rise to additional byproducts.

The α-methylene derivatives of phenylacetic acid, hydrocinnamic acid, and the saturated fatty acids from heptanoic through stearic acid as well as oleic acid were prepared. The melting points, boiling points, and yields of these as well as boiling points of some oxazolines are summarized in Table I. The acrylic acids are characterized by IR absorption at 1630 cm^{-1} for the vinyl group and at 1700 cm^{-1} for the carboxylic group.

Purification. We observed that the acrylic acids V were much less reactive than the parent fatty acids; hence,

Table I. Boiling Points of Oxazoline IV and Physical Constants and Yields of α-Substituted Acrylic Acids (CH_2=CRCOOH)

R	mp, °C	bp, °C (mm)	overall yield, %	bp, °C (mm), of oxazoline IV
C_6H_5	not isolated pure		70 (crude)	87-95 (0.2)
$C_6H_5CH_2$	66-68	170-174 (20)	80	
C_4H_9		107 (25)	75	78 (20)
C_5H_{11}		129 (15)	65	
C_6H_{13}		108 (20)	75	
C_7H_{15}		152-155 (14)	65	
C_8H_{17}		176 (20)	75	
$C_{10}H_{21}$	33-34	134-135 (0.25)	80	93 (0.02)
$C_{12}H_{25}$	43-44		80	140 (4)
$C_{14}H_{29}$	54-55		85	173 (0.26)
$C_{16}H_{31}$ (from oleic acid)		196-197 (0.4)	80	175 (0.1)
$C_{16}H_{33}$	50-60		80	173 (0.3)

the preparation of the methyl esters for chromatographic analysis required a substantially longer reaction time and more catalyst than the conventional method by Metcalfe and Schmitz.[12] This reduced reactivity was used to advantage in the purification of the acrylic acids. Brief reaction of the acrylic acids V with boron trifluoride–methanol (BF_3–$2CH_3OH$) converted the starting fatty acids to its methyl ester but left the acrylic acid unreacted. Separation of the fatty acid from the α-alkyl acrylic acid by either fractional distillation or recrystallization is difficult. Separation of the fatty acid methyl ester from the corresponding acrylic acid is readily accomplished by the two techniques mentioned above, and α-alkyl acrylic acids of 95% of higher purity could thus be obtained.

Experimental Section

Materials. Heptanoic acid, pelargonic acid, and paraformaldehyde were obtained through the courtesy of the Celanese Chemical Co., New York, NY.[13] Palmitic acid, 96%, was obtained from the Armak Division of Akzona, Inc., Chicago, IL. Oleic acid, 99%, was obtained from Applied Science Co., State College, PA. AMP was obtained through the courtesy of International Minerals and Chemical Corp., Des Plaines, IL. All other organic reagents were purchased from Aldrich Chemical Co., Milwaukee, WI.

Synthetic Procedures. The following four examples are typical of the general procedure.

Synthesis of α-Pentylacrylic Acid. Heptanoic acid (65 g, 0.5 mol) was stirred with AMP (89 g, 1 mol) in a flask provided with stirrer, thermometer, a 12-in. Vigreaux column, and a condenser set for downward distillation. The reaction mixture was heated for 5 h at such a rate that the vapor temperature on top of the column never exceeded 105 °C. The reaction temperature gradually rose to 180 °C. At the end of the 5-h period a sample was withdrawn for determination of free acid content, which was below 2%. A 10% alcoholic KOH solution (2.0 g, 0.4 mmol) was added, and refluxing was continued for 3 h. Excess AMP was removed by vacuum distillation through the Vigreaux column until the vapor temperature reached 103 °C (18 mm). IR analysis showed only traces of ester absorption at 1740 cm^{-1}. The distillate was diluted with 100 mL of water and extracted with 25 mL of hexane; the hexane was evaporated, and the residue of oxazoline II was returned to the reaction vessel. Paraformaldehyde (24.0 g, 0.8 mol) was added to the crude oxazoline II at 90 °C. This temperature was maintained for 30 min and then raised by 5 °C every half hour up to 115 °C. Cumene (100 mL) was added and the mixture was refluxed for 3 h at 180 °C.

Isothermal GLC analysis (170 °C) indicated the product contained 8.4% unreacted oxazoline II. Paraformaldehyde (1.8 g, 0.06 mol) and 10% alcoholic KOH (0.25 g, 0.5 mmol) were added to the product, which was heated stepwise from 90 to 115 °C, as described above, and refluxed for 1 h at 180 °C. GLC analysis indicated 4% oxazoline II. The product was transferred to a 1-L flask (foaming) and refluxed overnight with 200 mL of distilled water and 100 mL of concentrated HCl. The product was cooled to room temperature, and the bottom layer was drawn off and discarded. Hydrolysis was continued with 100 mL of distilled water and 50 mL of concentrated hydrochloric acid for 3 h. IR analysis of the top layer showed no secondary amide at 1520 cm^{-1}. The layers were separated as before, and the bottom layer was discarded. The product was washed once with 50 mL of distilled water to remove residual hydrochloric acid and then after the addition of 85% phosphoric acid (0.2 g, 2 mmol) was distilled through a 12-in. Vigreaux column under a water aspirator vacuum. The fraction boiling between 129 and 134 °C at 18 mm was collected. Toward the end of the distillation, the product was heated to 360 °C to decompose any estolide. Yield of the distillate was 45.0 g (0.3 mol). Weight of the residue was 11 g.

Purification of α-Pentylacrylic Acid. A 20-g sample of distilled acid containing 14% of unreacted heptanoic acid was treated at room temperature (22 °C) with 100.0 g (3.1 mol) of absolute methanol and 0.4 g (4 mmol) of a BF_3–$2CH_3OH$ complex. After standing for 1 h, the product was washed with 100 mL of water, and the layers were separated. The water layer was extracted twice with 100-mL portions of hexane. The combined organic layers were freed from hexane by evaporation, and the residue was fractionally distilled. The 2.7-g forerun, vapor temperature 77–120 °C (20 mm), contained mostly the methyl ester of the saturated acid. The residue (15.40 g, 0.11 mol) contained 98% acid by titration and consisted of 97% α-pentylacrylic acid by GLC analysis.

Synthesis of α-Tetradecylacrylic Acid. Palmitic acid (128.2 g, 0.5 mol) was stirred with AMP (89 g, 1 mol) in a 1-L flask provided with stirrer, thermometer, and a 12-in. Vigreaux column. The reaction mixture was heated for 8.5 h at such a rate that the vapor temperature on top of the column never exceeded 105 °C. The reaction temperature gradually rose to 188 °C. The free fatty acid content of the products after the heating period was 1.8%. A 10% alcoholic potassium hydroxide solution (2.0 g, 3.6 mmol) was added, and heating as described above was continued for 3 h. The excess AMP was removed by vacuum distillation at about 20 mm. IR analysis of the crude oxazoline II showed no evidence of ester. Any remaining free fatty acid was neutralized with additional 10% KOH solution. The crude II was heated to 90 °C, and 24 g (0.8 mol) of paraformaldehyde was added. The temperature was maintained at 90 °C for 30 min and raised by 5 °C increments every half hour up to 115 °C. Cumene (100 mL) was added, and the mixture was refluxed for 2.5 h at 187 °C. Isothermal GLC (290 °C) indicated that the product still contained 17% of oxazoline I. Paraformaldehyde (3.4 g, 0.1 mol) was added, and the heating and reflux procedures were repeated. The product, containing 5% starting oxazoline, was freed from cumene by vacuum distillation at 20 mm up to a maximum flask temperature of 115 °C. The oxazoline IV was then distilled at 142–152 °C (0.05 mm). Yield was 142.0 g (0.44 mol), 84.7% of theory. The residue weighed 21 g.

The distilled oxazoline was hydrolyzed by refluxing overnight (16.5 h) with a mixture of 100 mL of concentrated HCl, 250 mL of distilled water, and 75 mL of glacial acetic acid (105 °C). The

(12) Metcalfe, L. D.; Schmitz, A. A. *Anal. Chem.* **1961**, *33*, 363.

(13) Reference to brand or firm name does not constitute endorsement by the U.S. Department of Agriculture over others of a similar nature not mentioned.

layers were separated, and the top layer was refluxed with a mixture of 50 mL of concentrated HCl, 100 mL of distilled water, and 30 mL of glacial acetic acid for 6 h. At this point, IR analysis showed no absorption at 1500 cm^{-1}. The top layer was placed in a rotary evaporator, and acetic acid and water were removed at 80 °C at 0.1 mm. The crude acid weighed 112.0 g (0.4 mol), 83.5% of theory. The product contained 96% fatty acid by titration but about 14% unreacted palmitic acid by GLC analysis of the methyl ester.

Purification of α-Tetradecylacrylic Acid. A sample of crude α-tetradecylacrylic acid (110 g, 0.4 mol) containing 14% unreacted palmitic acid was treated with 400 mL of methanol and 2.5 g (0.25 mmol) of BF_3–$2CH_3OH$, the mixture was allowed to stand for 2 h at room temperature, 10 g (0.02 mol) of 10% alcoholic KOH was added, the solvent was removed in a rotary evaporator, and the residue was recrystallized from 750 mL of acetone at −10 °C. Yield was 71.0 g (0.26 mol) of the desired acrylic acid, mp 49.5–50 °C, 95% pure by titration and 95% pure by GLC analysis. Analysis by UV at 206 nm of a 0.01% solution in absolute alcohol confirmed the above determination of purity.

Preparation of α-Phenylacrylic Acid. A mixture of 89.0 g (1 mol) of AMP and 68.1 g (0.5 mol) of phenylacetic acid was heated for 5 h as described above. The temperature of the reaction mixture rose gradually to 176 °C. At the end of the heating period, the free fatty content was 0.6%. The excess AMP was removed by vacuum distillation (20 mm) until the vapor temperature had risen to 105 °C. IR analysis showed only a trace of ester.

To the crude oxazoline II, 2.0 g (3.6 mmol) of 10% alcoholic potassium hydroxide and 0.3 g (3 mmol) of hydroquinone were added. After paraformaldehyde (24 g, 0.8 mol) was added at 70 °C, the temperature rose during 15 min to 81 °C. After cooling, the reaction mixture was kept at 70 °C for 45 min. Xylene (180 mL) was added and the mixture was refluxed through a Dean-Stark trap for 2.5 h. GLC analysis showed the presence of 22% unreacted oxazoline II. To the product at 70 °C was added 0.2 g (2 mmol) of hydroquinone, 0.1 g (0.2 mmol) of 10% alcoholic potassium hydroxide, and 4.5 g (0.15 mol) of paraformaldehyde. The mixture was heated at 70 °C for 1 h and then refluxed for 30 min. GLC analysis showed 3.7% oxazoline II content. Xylene was removed with water aspirator vacuum, and the product was distilled at 87–95 °C at 0.2 mm. Yield was 69.0 g (0.26 mol), 69% of theory. Hydroquinone (0.3 g, 3 mmol) was added to the freshly distilled oxazoline IV.

To 56.0 g (0.21 mol) of oxazoline IV were added 50 mL of concentrated hydrochloric acid, 100 mL of distilled water, and 35 mL of glacial acetic acid. The mixture was refluxed in a nitrogen atmosphere for 16 h. To the cooled product, 150 mL of methylene chloride was added, and, after this was stirred for 5 min, the bottom layer was separated. The organic layer was returned to the reaction flask, and 25 mL of concentrated hydrochloric acid, 50 mL of distilled water, and 20 mL of acetic acid were added. The methylene chloride was distilled off, and the reaction mixture was refluxed for 3.5 h. Methylene chloride (150 mL) was added, the mixture was shaken, and the layers were separated as before. The product was dried in a rotary evaporator by removal of methylene chloride and most of the acetic acid. The gummy residue was dissolved in 150 mL of methylene chloride; 100 mL of distilled water containing 25 g (0.3 mol) of 50% sodium hydroxide solution was added slowly with good agitation. The methylene chloride layer was then separated and evaporated to dryness. The 12-g residue showed a high ester content by IR analysis. The aqueous solution of the sodium salt of the desired acid was neutralized with about 25 mL of concentrated hydrochloric acid; 150 mL of methylene chloride was added to dissolve the gummy precipitated acid. The solvent was removed by evaporation, and the residue was dried in a vacuum oven. The crude product contained 90% acid by titration but could not be purified further by distillation or recrystallization.

Synthesis of α-Benzylacrylic Acid. Hydrocinnamic acid (75 g, 0.5 mol) and AMP (89.0 g, 1 mol) were heated for 6 h in a 1-L flask provided with stirrer, thermometer, and a 12-in. Vigreaux column. To the product, essentially free of acid, was added 2 g (3.6 mmol) of 10% alcoholic KOH and the heating was continued for 2 h. IR analysis showed no ester. Excess AMP (40 g, 0.5 mol) was removed under a 25-mm vacuum.

To the crude oxazoline II, paraformaldehyde (24 g, 0.8 mol) was added at 70 °C. After the mixture was heated at that temperature for 1 h, the reaction was 61.5% complete as shown by GLC (230 °C). The product was then heated at 80 °C for 90 min and GLC analysis indicated that the reaction was 75.1% complete. After 1 h at 90 °C, the reaction was 89.2% complete. Xylene (75 mL) was added, and the mixture was refluxed for 2 h. The product contained 12.4% starting oxazoline by GLC analysis. Paraformaldehyde (3 g, 0.1 mol) was added at 70 °C, and the product was heated at that temperature for 1 h. Heating was continued at 80 °C for 1 h and then at 90 °C for 1 h. GLC analysis indicated that the reaction was 93.0% complete. The product was refluxed for 2 h and then contained 96.7% oxazoline IV by GLC.

Xylene was removed under vacuum, and the crude oxazoline IV was refluxed overnight with a mixture of 100 mL of concentrated HCl, 230 mL of distilled water, and 75 mL of acetic acid. The layers were separated, and the aqueous layer was extracted with 100 mL of dichloroethane; this was evaporated, and the residue was added to the organic layer of crude α-benzylacrylic acid. The latter was refluxed with 50 mL of concentrated HCl, 125 mL of distilled water, and 37.5 mL of acetic acid for 3 h. At this point, IR analysis indicated absence of secondary amide absorption at 1520 cm^{-1}. The layers were separated, the aqueous layer was extracted with 50 mL of dichloroethane, and the extract and organic layer were combined. Solvent, water, and acetic acid were removed by vacuum distillation. Phosphoric acid (85%, 1 g, 0.01 mol) was added, and the α-benzylacrylic acid was distilled at 170–174 °C at 20 mmHg. Yield was 58.5 g (0.36 mol), 72% of theory. Weight of residue was 10 g. This product contained 97% acid by titration and 93.6% α-benzylacrylic acid by GLC analysis of its methyl ester. A portion of the product, which solidified on standing, was recrystallized from hexane and melted at 66–68 °C. Its acid number corresponded to theory, and it was 99% pure by GLC analysis by its methyl ester.

Analytical Procedures. The progress of the formaldehyde addition to II and subsequent dehydration to IV was followed by isothermal GLC in a Hewlett-Packard 810 instrument with an 8-ft stainless steel column packed with 20% UCW-98 on 60–80-mesh Chromosorb W. The oven temperature was held at 160 °C for the hexanoic acid derivative and was raised by 10 °C for each additional carbon atom in the alkyl side chain. The methylol derivatives IIIa prepared from hexanoic and heptanoic acid were separated readily chromatographically from II and IV. The methylol derivatives of the higher molecular weight oxazolines dehydrated on the column to form IV.

The methyl esters of the desired acids V were prepared by a modification of the method of Metcalfe and Schmitz[12] in the following manner. A 1-g sample of V was refluxed with 10 mL of absolute methanol in the presence of 0.2 mL (2 mmol) of BF_3–$2CH_3OH$ for 5–6 h. The solution was then analyzed chromatographically in the conventional manner. The equivalent weights of all the acrylic acids were found to be within 3% of theory.

Registry No. II (R = C_5H_{11}), 51849-53-7; II (R = Ph), 1569-08-0; IV (R = Ph), 78763-97-0; IV (R = $C_6H_5CH_2$), 78763-98-1; IV (R = C_4H_9), 78763-99-2; IV (R = $C_{10}H_{21}$), 78764-00-8; IV (R = $C_{12}H_{25}$), 78764-01-9; IV (R = $C_{14}H_{29}$), 78764-02-0; IV (R = $C_{16}H_{31}$), 78764-03-1; IV (R = $C_{16}H_{33}$), 78764-04-2; V (R = C_6H_5), 492-38-6; V (R = $C_6H_5CH_2$), 5669-19-2; V (R = C_4H_9), 4380-88-5; V (R = C_5H_{11}), 4436-84-4; V (R = C_6H_{13}), 3760-10-9; V (R = C_7H_{15}), 1118-91-8; V (R = C_8H_{17}), 69858-94-2; V (R = $C_{10}H_{21}$), 52756-21-5; V (R = $C_{12}H_{25}$), 33785-92-1; V (R = $C_{14}H_{29}$), 6818-50-4; V (R = $C_{16}H_{31}$), 33780-98-2; V (R = $C_{16}H_{33}$), 6818-51-5; heptanoic acid, 111-14-8; palmitic acid, 57-10-3; phenylacetic acid, 103-82-2; hydrocinnamic acid, 501-52-0; AMP, 124-68-5.