pentane extract prior to distillation.

Determination of the Rate of Hydroboration. The hydroboration was carried out on 10-mmol scale in the same manner as described for the preparation of **3a**. At definite intervals of time 2.0-mL aliquots were hydrolyzed as described elsewhere.[27] From the volume of hydrogen liberated, the residual active hydride content in the reaction mixture could be calculated.

Oxidation of Initial Hydroboration Product and GLC Analysis. In a 50-mL reaction flask equipped with a reflux condenser, a 4.0-mL aliquot (2.0 mmol) was introduced with a syringe. Then 10 mL of THF and 2 mL of water were added. The flask was cooled in ice bath and 2 mL (6 mmol) of 3 N NaOH solution was added, followed by a dropwise addition of 1.0 mL (8 mmol) of 30% hydrogen peroxide. After the initial vigorous reaction subsided, the flask was maintained at 50 °C for 2 h. The aqueous layer was saturated with anhydrous potassium carbonate, and the organic layer was used for GLC analysis, in order to determine the relative amounts of 1,4- and 1,5-cyclooctanediols. Whenever the yield of these diols was to be determined, an internal standard, usually *n*-tetradecane, was added during the oxidation step.

Two drops of the THF solution from the oxidation experiment were taken in a vial, and 0.1 mL of dry pyridine and 0.1 mL (excess) of *N,O*-bis(trimethylsilyl)acetamide (BSA) were added. The mixture was thoroughly shaken and heated for 5 min. The resulting solution containing the silyl derivatives of the diols was analyzed by GLC. A 6 ft × $^1/_8$ in. column packed with 5% SE-30 deposited on Varaport-30 was used to estimate the overall yield of the diol mixture and an 18 ft × $^1/_8$ in. column packed with 5% neopentylglycol adipate on Varaport-30 was employed for the separation of the silyl derivatives of the isomeric diols.

Preparation of Bicyclo[3.3.1]nonan-9-one (6). In a 500-mL reaction flask 10.9 g (50 mmol) of **3a** was dissolved in 50 mL of CH₂Cl₂ at room temperature and 21.7 mL of a 2.3 M solution (50

mmol) of 2,6-dimethylphenol in CH₂Cl₂ was added dropwise with stirring. After 0.5 h, the solvent was completely pumped off and 25 mL of dry THF was added. The flask was then cooled in ice bath, and 6.3 g (5.0 mL, 55 mmol) of α,α-dichloromethyl methyl ether was added, followed by slow, dropwise addition of 62.5 mL of a 1.6 M solution of lithium triethylcarboxide (100 mmol) in hexane. The reaction mixture was stirred for 2 h at room temperature. To this flask were added 40 mL of ethanol, 8.0 g of solid sodium hydroxide, and 10 mL of water. The flask was cooled to 0 °C and 20 mL of 30% hydrogen peroxide was added dropwise, maintaining the temperature below 50 °C. After the initial vigorous reaction subsided, the mixture was heated for 2 h at 50 °C. The aqueous phase was saturated with sodium chloride, the organic phase was removed and washed once with 25 mL of saturated salt solution, and the solvents were removed on a rotary evaporator. The resulting liquid was diluted with 50 mL of pentane, the phenol extracted with 3 N aqueous sodium hydroxide (2 × 25 mL), and the pentane solution washed with 25 mL of saturated salt solution. Pentane was removed under reduced pressure, followed by triethylcarbinol (bp 54–56 °C (16 mmHg)), and the semisolid residue was dissolved in 40 mL of pentane. The solution was cooled to –78 °C. Filtration, followed by washing with cold (–78 °C) pentane, gave 4.9 g (71% yield) of colorless crystals, mp 152–153 °C. On recrystallization from pentane a product, mp 155–156 °C, was obtained (lit.[23] mp 154.5–156.5 °C).

Registry No. 1, 36594-41-9; 2 (X = Cl), 63348-81-2; 2 (X = Br), 55652-52-3; 2 (X = I), 55652-50-1; 3 (X = Cl)·OEt₂, 70160-57-5; 3 (X = Cl)·SMe₂, 70160-58-6; 3 (X = Br)·SMe₂, 70160-59-7; 3 (X = I)·SMe₂, 70160-56-4; 4 (X = Cl)·OEt₂, 70145-36-7; 4 (X = Cl)·SMe₂, 70145-37-8; 4 (X = Br)·SMe₂, 70145-39-0; 4 (X = I)·SMe₂, 70145-41-4; 5 (X = Cl), 22086-34-6; 5 (X = Br), 22086-45-9; 5 (X = I), 70145-42-5; 6, 17931-55-4; COD, 111-78-4.

Preparation of Hindered Esters by the Alkylation of Carboxylate Salts with Simple Alkyl Halides

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Sterically hindered esters were prepared in excellent yields by the use of anion-exchange resins in both biphase and triphase systems. In addition, quantitative yields of a variety of esters were obtained by the displacement reactions of simple aliphatic and aromatic potassium carboxylate salts and alkyl halides in acetone or acetone–water mixtures. Esters prepared in quantitative yields include ethyl hexadecanoate in 95% acetone and ethyl 2,-4,6-trimethylbenzoate, 1-methylheptyl 2,4,6-trimethylbenzoate, and ethyl 9,10-epoxyoctadecanoate in pure acetone. The second-order rate constant for the reaction of potassium 2,4,6-trimethylbenzoate with iodoethane in 95% acetone was found to be 2.67 × 10⁻⁴ mL⁻¹ s⁻¹ at 40 °C.

Classical acid-catalyzed esterification methods are of little value in the preparation of sterically hindered esters.[2] The displacement reaction of alkali metal carboxylate salts would seem to be a suitable method for the preparation of these esters. However, there are several reports that this reaction with unactivated halides is not suitable for the preparation of even ordinary esters,[3,4] giving poor yields

and conversions along with much elimination.[4] To avoid these supposed problems, hindered esters have been prepared by nucleophilic displacement by carboxylate anions on compounds such as alkyl chlorosulfites,[5] trimethylanilinium salts,[6] triethyloxonium fluoroborates,[7] dimethyl sulfate,[8] and benzyl and allyl halides,[9] all of which

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Table I. Esterification on Anion-Exchange Resins

acid	halide	resin	temp, °C	time, h	solvent[a]	procedure[b]	ester yield
2-ethylhexadecanoic	iodoethane	IRA-900	25	22	D	C	93[c]
2,2-dimethylhexadecanoic	iodoethane	IRA-900	25	22	D	C	90[c]
2,4,6-trimethylbenzoic	iodoethane	IRA-900	25	20	D	C	55[c]
3,3-dimethylbutanoic	iodoethane	AG1-8X	25	20	M	C	84[c,d]
2,4,6-trimethylbenzoic	iodoethane	AG1-8X	25	20	M	C	59[b]
2,4,6-trimethylbenzoic	iodoethane	AG1-8X	65	20	M	A, B	94[c,e]
2,4,6-trimethylbenzoic	iodoethane	none	65	20	M	E	86[f,g]
2,4,6-trimethylbenzoic	1-bromobutane	AG1-8X	69	25	H	A	8[f]
2,4,6-trimethylbenzoic	iodoethane	AG1-8X	69	2.25	H	A	41
2,4,6-trimethylbenzoic	iodoethane	AG1-8X	69	20	H	A	97[f]
2,4,6-trimethylbenzoic	2-iodopropane	AG1-8X	69	95	H	A	23[f]
9,10-epoxyoctadecanoic	iodoethane	IRA-900	69	20	H	A	92[c]

[a] D = diethyl ether, M = methanol, H = hexane. [b] Procedure A, hydroxide form of the resin was in excess; procedure B, carboxylate salt of the resin was prepared in situ; procedure C, the resin was treated with excess carboxylic acid and the excess acid was washed off; procedure E, no resin was used. [c] Isolated yield based upon acid salt. [d] 5% methyl ester also formed (NMR). [e] No methyl ester formed (NMR). [f] GLC yield. [g] 5% of salt converted to acid during run.

have readily displaceable leaving groups. Alternatively, methods which increase the nucleophilicity of the carboxylate anion, including the use of crown ethers,[10,11] polyamines,[12] and polar aprotic solvents[13-15] such as hexamethylphosphoramide (HMPA) and dimethyl sulfoxide (Me₂SO), have been applied in the preparation of hindered esters.[13,14] Although organic ammonium salts have been widely used in esterification procedures to solubilize carboxylate salts and to transfer them into aprotic solvents,[16,17] the successful results obtained with these salts for the preparation of hindered esters have been reported only as a private communication.[18]

In contrast with published reports,[3,4] we find that esters may be prepared readily in excellent yields from simple alkyl halides and carboxylate salts under a wide variety of conditions accompanied by little or no elimination. We employed three fundamentally different methods. In two of these, anion-exchange resins were used either as biphase or as triphase catalysts.[19] Alternatively, we carried out the displacement reaction in ordinary hydroxylic or aprotic solvents such as methanol, acetone, and water–acetone without an anion-exchange resin.

The use of the anion-exchange resin combines the advantages obtained by using ordinary quaternary ammonium salts[16,17] without the difficulties involved in removal of these organic soluble salts. In this procedure, the recovery of the polymeric catalyst is accomplished simply by filtration. Another major advantage of this procedure is that it does not require finding a solvent to dissolve a carboxylate salt. Anion-exchange resins have been used

by two research groups, apparently independently,[20,21] to prepare unhindered esters. We report the application of the biphase method (procedures A–C) for the preparation of sterically hindered esters and an acid-sensitive ester.

The hydroxide form of the anion-exchange resin was treated with a carboxylic acid by a column technique to give the carboxylate salt of the resin. Under the conditions normally used (procedure A), the acid was held quantitatively on the column. The resin was then transferred to the reaction flask and allowed to react with the alkyl halide under the conditions given in Table I. The product, identified by IR, ¹H NMR, and GLC, was isolated by filtration and evaporation of the solvent.

Even though the yields reported in Table I are often excellent with iodoethane, they are poor with the less reactive halide, bromobutane, and the secondary halide, 2-iodopropane. This suggests that a relatively slow rate is the limiting factor when the yields are low. That possible competing reactions, namely, solvolysis and elimination, did not occur to a limited extent during the alkylation reactions was demonstrated by the following experiment (procedure C). A partially base-exchanged resin was treated with an excess of carboxylic acid (as compared with the hydroxide ion on the resin) so that more than half of the carboxylic acid was not exchanged, and this unexchanged acid was eluted from the column by washing. This acid-exchanged resin after alkylation with iodoethane gave a product containing only traces (0–2%) of carboxylic acid. If either elimination or solvolysis of the halide had occurred during the reaction, these reactions would have transformed the carboxylic salt of the resin into the unreactive carboxylic acid as a byproduct. Therefore, when low yields are obtained by this technique with iodoethane, it is undoubtedly the result of an incomplete reaction.

Solvent polarity does not affect the yield significantly with this method. For example, in hexane, the 2,4,6-trimethylbenzoate salt reacted at elevated temperatures with iodoethane to give ethyl 2,4,6-trimethylbenzoate in an isolated yield of 97%, whereas the yield in methanol was 94%. The product obtained from methanol was shown by NMR to contain none of the methyl ester. However, a small amount of the methyl ester (5%) was observed when the less hindered ethyl 3,3-dimethylbutanoate was prepared by this method in methanol.

Anion-exchange resins have been employed recently as triphase catalysts in nucleophilic displacements on alkyl

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Table II. Esterification of Sodium 2,4,6-Trimethylbenzoate by Triphase Catalysts (Procedure D)

reactant	resin	temp, °C	time, h	organic solvent	% yield ester
1-bromobutane	none	75	95	toluene	7^a (1^c)
1-bromobutane	AG1-8X	75	92	toluene	53^a (1.5^c)
1-bromobutane	1^d	75	92	toluene	93^a ($<0.5^c$)
iodoethane	1^d	70	24	benzene	85^b
iodoethane	1^d	25	36	benzene	15^b (0.3^c)

^{a} GLC yield. ^{b} Isolated yield based upon carboxylate salt. ^{c} Percent of carboxylate salt converted to acid during the reaction. ^{d} Resin prepared from N,N-dimethyl-1-octanamine and chloromethylated polystyrene.

Table III. Alkylation of Potassium Carboxylate Salts in Acetone^a

acid	halide	solvent	product	% yield^b
hexadecanoic^c	iodoethane	acetone	ethyl hexadecanoate	50
hexadecanoic^d	iodoethane	95% acetone	ethyl hexadecanoate	100
octadecanoic^c	iodoethane	acetone	ethyl octadecanoate	18
octadecanoic^d	iodoethane	95% acetone	ethyl octadecanoate	95
cis-9-octadecenoic^d	iodoethane	95% acetone	ethyl cis-9-octadecenoate	100
2-ethylhexadecanoate^c	iodoethane	acetone	ethyl 2-ethylhexadecanoate	100
2,4,6-trimethylbenzoic^c	iodoethane	acetone	ethyl 2,4,6-trimethylbenzoate	100
2,4,6-trimethylbenzoic^c	2-iodopropane	acetone	isopropyl 2,4,6-trimethylbenzoate	96
2,4,6-trimethylbenzoic^d	2-iodooctane	acetone	1-methylheptyl 2,4,6-trimethylbenzoate	74^e
2,4,6-trimethylbenzoic^c	2-iodooctane	acetone	1-methylheptyl 2,4,6-trimethylbenzoate	100
2,4,6-trimethylbenzoic^c	iodoethane	95% acetone	ethyl 2,4,6-trimethylbenzoate	$<10^f$
9,10-epoxyoctadecanoic^d	iodoethane	acetone	ethyl 9,10-epoxyoctadecanoate	$100^{g,h}$

^{a} Reaction run for 16 h in refluxing solvent (56 °C). ^{b} GLC yield based on acid or acid salt. ^{c} Carboxylate salt prepared in situ with excess potassium carbonate (procedure F). ^{d} Carboxylate salt prepared in advance. No excess base was used. ^{e} An aliquot removed before acidification also gave 26% acid and 74% ester. Compare with 36% elimination found for 2-bromooctane at 60 °C in HMPA.[13b] ^{f} Yield by IR. ^{g} Isolated yield, >99% epoxidized. ^{h} 95% epoxidized when run in 95% acetone.

halides by cyanide, halide, and alkoxide ions,[19] but this procedure had not been reported previously with carboxylate anions. Sodium 2,4,6-trimethylbenzoate in water and alkyl halide in the organic phase were heated with an anion-exchange resin which was suspended at the interface of the two solvent phases. We used two different catalysts with this procedure. The triphase catalyst (chloride form) 1 was prepared by heating N,N-dimethyl-1-octanamine with a polystyrene polymer, which had only about 8% of the aromatic rings chloromethylated and 1% divinylbenzene cross-linking. With this polymer, 1, n-butyl 2,-4,6-trimethylbenzoate was obtained from the acid salt and n-butyl bromide in 93% yield. Under similar conditions, the chloride form of Bio-Rad AG1-8X,[22] an anion-exchange resin with considerably more aromatic ring substitution and 8% divinylbenzene cross-linking, gave only a 53% ester yield even though the number of catalytic sites available was double that of the previous run. Although these results are consistent with Regen,[19] who found that resins with the least aromatic substitution are most efficient, the ion selectivity of the resin may also play a role in this particular case. In general, anion-exchange resins show a preference for halide ions over carboxylate anions such as acetate.[23] Therefore, the least selective resin should make the best catalyst. Since the selectivity of anion-exchange resins decreases with increasing cross-linking,[24] it is not unreasonable that the resin with the least cross-linking was the better catalyst for this particular system.

A control reaction carried out without any resin catalyst gave only a 7% yield of ester, showing clearly the effectiveness of the catalyst. With either catalyst the rates of

hydrolysis and elimination were much slower than the alkylation reaction, as evidenced by the fact that little carboxylic acid was formed (Table II).

Although it has long been believed that the displacement reaction of alkali carboxylate salts with unactivated halides is unsuitable as a preparative method,[3,4] recent improvements in this process involving the use of polar aprotic solvents such as HMPA and Me₂SO have increased the nucleophilicity of the carboxylate anion, thereby giving excellent yields of esters.[13,14] Pfeffer and Silbert[13b] have shown that in HMPA-ethanol the rate of alkylation actually increases slightly with increased hindrance of the carboxylate anion. However, both HMPA and Me₂SO have the disadvantages of high boiling point and physiological hazard.[25] Acetone has been employed as such an aprotic solvent for only two relatively unhindered acids, one steroidal[26] and one terpenoid,[27] but its use for the preparation of esters from simple aliphatic or aromatic esters has not been reported. When 2,4,6-trimethylbenzoic acid was refluxed in acetone with excess potassium carbonate and excess iodoethane, a quantitative yield of the ethyl ester was obtained (Table III). The reaction is sufficiently rapid that even a secondary halide, 2-iodooctane, also gave a quantitative yield. This extremely simple procedure is well suited for branched long-chain fatty acids because their potassium salts are generally soluble in acetone. For example, 2-methylhexadecanoic acid gave a quantitative yield of the ethyl ester. In contrast, the potassium salts of octadecanoic and hexadecanoic acid have very low solubility in this solvent and gave yields of 18 and 50%, respectively.

By a slight modification of the alkylation procedure above, excellent yields of esters can be obtained even with long-chain fatty acids, such as octadecanoic acid. Po-

(22) 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.

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Table IV. Reaction of Potassium
2,4,6-Trimethylbenzoate with Iodoalkanes

solvent	temp, °C	RI	$10^4 k^a$
95% acetone	40	iodoethane	2.67
92.5% acetone	40	iodoethane	1.52
Me₂SO	60	1-iodopentane	11 700[b]

[a] Units are $mL^{-1} s^{-1}$. [b] Calculated[13b] from the rate of 1-chlorohexane in Me₂SO with relative rates of 1-iodopentane and 1-chlorohexane measured in HMPA.

tassium octadecanoate refluxed with ethyl iodide in 95% acetone gave a 95% yield of ester (compare with 18% in 100% acetone). In aqueous acetone an excess of base is harmful and should be avoided.

This method of esterification in acetone gave a quantitative yield with cis-9,10-epoxyoctadecanoic acid. The oxirane is so sensitive to acid that the ordinary Fischer method of esterification is not feasible. That treatment of this acid with KOH formed the potassium salt without any ring opening was shown by titration of both the carboxylate groups[28] and the oxirane ring[29] with HBr in acetic acid. The ethyl cis-9,10-epoxyoctadecanoate, obtained without purification, was shown to be of high purity by IR, analysis for the oxirane ring (>99%),[29] and its melting point.

The quantitative yield obtained here and for potassium cis-9-octadecenoate, with no excess base present, shows that elimination is not a significant problem in the alkylation of carboxylate salts with iodoethane. Therefore, in these runs with excess potassium carbonate added, the base serves only to convert the original acid into the salt, and the excess base was not necessary for a high yield. However, with a secondary halide, such as 2-iodooctane, some elimination does occur and the excess base and excess halide are required for a quantitative yield.

The second-order rate constants for the reaction of potassium 2,4,6-trimethylbenzoate were measured in 95% acetone and 92.5% acetone (Table IV). The slowing of the rate with increasing concentration of water is as expected, since the increased solvation of the carboxylate anion should increase the activation energy. Assuming that the reaction rate doubles for each 10 °C temperature increase, the esterification rate in acetone is estimated to be 10^2–10^3 times slower than in dimethyl sulfoxide.[30] This is not unreasonable in view of the 300-fold rate difference for these two solvents found for phenoxide displacement.[31]

Of the three methods studied here, the reaction of the potassium carboxylate salts with alkyl halides in acetone or aqueous acetone (procedures F and G) is the method of choice as a synthetic technique. The method is preferable to previously reported methods and the other procedures reported here in terms of its simplicity, safety, and yield. The method appears to be general in that aliphatic, aromatic, hindered, and acid-sensitive esters have been successfully obtained by using this technique. The quantitative yield obtained with a secondary halide gives this method a clear advantage over the biphase method, which is apparently too slow to be practical with these halides. Although we have used only alkyl iodides, the rapid rate of alkylation suggests that bromides and

chlorides may also be employed in either procedure F or G.

In comparison with the above, the biphase method is somewhat less convenient. A tedious preliminary step, the treatment of the resin with a considerable excess of sodium hydroxide (procedures A and B), is necessary to replace a reasonable fraction of the chloride ions, since anion-exchange resins normally show a preference for the halide ion over the hydroxide ion (Cl⁻ > acetate > ⁻OH).[23] The subsequent exchange of the hydroxide ion by the carboxylate anion is favorable and readily accomplished. This method may be advantageous for water-soluble or water-sensitive esters, since no water is used during the very simple alkylation and isolation procedures.

The triphase technique shows promise as a simple method for the preparation of esters. Only catalytic quantities of resin are employed and the exchange of the carboxylate anion takes place as the reaction proceeds. Although this procedure is excellent for preparation of 2,4,6-trimethylbenzoate esters, no attempts were made to demonstrate the generality of this reaction.

Experimental Section

The ¹H NMR spectra were taken on a JEOL C-60H, IR spectra on a Perkin-Elmer 237B spectrophotometer, and GLC analyses on a Hewlett-Packard 7620A chromatograph equipped with a Columbia Scientific Industries Supergrator-2 programmable integrator, with a 6 ft × ¹/₈ in. column of 7.5% EGA and 2% H₃PO₄ on Anakrom ABS. The 2-methylhexadecanoic and 2,2-dimethylhexadecanoic acids were prepared by the method of Pfeffer, Silbert, and Chirinko[32] in THF–HMPA and in THF, respectively. The IRA 900 (chloride form) was obtained from Rohm & Haas.

Biphase Esterification on Anion-Exchange Columns. Procedure A. The anion-exchange resin (chloride form of Bio-Rad AG1-8X, 100–200 mesh, 6.3 dry g, 3.2 mequiv/dry g) was partially exchanged on a column with 65 mL of 1 M sodium hydroxide. [When IRA-900 (8.1 dry g of resin, 4.2 mequiv/g) was used, it was treated with 100 mL of 1 M NaOH.] After the column was washed to neutrality with distilled water and then with methanol, a solution of the carboxylic acid (8.0 mmol) in methanol was slowly percolated through the column. The column was rinsed with methanol and then, if needed, washed successively with ether and hexane. The acid was quantitatively held on the resin.

The resin was transferred to a round-bottom flask and the total volume was adjusted to 25 mL with the reaction solvent (50 mL with IRA-900). Excess halide (32 mmol) was added and the mixture was magnetically stirred. At the end of the reaction period (Table I), the resin was filtered off and the solvent was removed on a rotary evaporator. The resulting product was analyzed by IR, GLC, and NMR.

Procedure B. This procedure was identical with procedure A except that the carboxylate salt of the resin was not prepared on a column. The hydroxide form of the resin, previously washed with water and methanol, was transferred with methanol into the reaction flask, and the volume was adjusted to 25 mL with methanol. The carboxylic acid was added, the solution was stirred for 15 min, and then the alkyl halide was added.

Procedure C. This procedure differed from procedure A only in that the resin was treated with 1 equiv of sodium hydroxide/equiv of resin. A significant portion of the carboxylic acid was not retained on the resin when it was washed carefully with methanol. After recovery of the acid, the amount of halide was adjusted for, and the yields were based upon, the acid retained on the resin. The ester product contained 0–2% carboxylic acid.

Triphase Esterification. Preparation of the Triphase Catalyst (1). Chloromethylated polystyrene beads with 1% divinylbenzene cross-linking (Bio-Beads, S-X1, 4.8 g of resin, 0.89 mequiv of Cl/g) were refluxed for 5 days in 35 mL of dry benzene with N,N-dimethyl-1-octanamine (0.78 g, 5.0 mmol). The resin

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(30) Assuming also that the rate increases linearly with acetone concentration from 92.5 to 100% acetone and that (rate ethyl)/(rate pentyl) = 2.3 and using the assumptions made in ref 12b gives (rate in Me₂SO)/(rate in acetone) ≃ 200.

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(1) was washed with benzene and dried under vacuum.

Triphase Esterification. Procedure D. Sodium 2,4,6-trimethylbenzoate (6.0 mmol), neutralized with sodium hydroxide to a phenolphthalein end point, was dissolved in 6 mL of water, and the solution was placed in a test tube (200-mm o.d.) fitted with a reflux condenser. To this solution was added the triphase catalyst (0.16 g of 1) and the alkyl halide (24 mmol) in 6 mL of organic solvent. The bottom layer was magnetically stirred, but the catalyst at the interface was not visibly disturbed. At the end of the reaction period, the mixture was made strongly acidic with hydrochloric acid and the yield was determined by GLC with the remaining carboxylic acid used as an internal standard. When AG1-8X (chloride form) was used as the catalyst, 0.090 dry g of resin (3.2 mequiv/dry g) was used.

Esterification without Anion-Exchange Resins. Procedure E. Esterification in Methanol. The alkali metal carboxylate salt (6 mmol was dissolved in 20 mL of methanol. Excess alkyl halide (32 mmol) was added. After the reaction period was over, the mixture was analyzed by GLC for both carboxylic acid and ester by use of an internal standard.

Esterification in Acetone with Added Potassium Carbonate. Procedure F. The carboxylic acid (2.0 mmol), the alkyl halide (8.0 mmol), anhydrous potassium carbonate (0.7 g, 5.0 mmol), 15 mL of acetone, and a magnetic stirring bar were placed in a round-bottom flask fitted with a drying tube. After the reaction period was completed (Table III), the cooled reaction mixture was acidified with dilute hydrochloric acid and extracted with CH_2Cl_2. GLC analysis was used to determine the yield with the unreacted acid used as an internal standard.

Alkylation of Potassium Carboxylates with No Excess Base. Procedure G. This procedure is identical with procedure F with the following exceptions. The potassium salt, prepared in advance, recrystallized from ethanol and dried under vacuum, was added to acetone or 95% acetone–water. No potassium carbonate was added.

Potassium cis-9,10-epoxyoctadecanoate, prepared from cis-9,10-epoxyoctadecanoic acid and KOH in ethanol, was shown to be 100% epoxidized.[27,28] The hydrochloric acid was omitted for

the workup of ethyl cis-9,10-epoxyoctadecanoate, and the isolated ester was identified by IR, analysis for the oxirane ring, and its mp, 21–22 °C (lit.[33] mp 21 °C), determined without purification.

Kinetic Measurements. The second-order rate constants were determined by the method of Pfeffer and Silbert.[13b] Potassium 2,4,6-trimethylbenzoate (about 0.20 M) in the appropriate acetone–water mixture and ethyl iodide (0.873 M) in 95% acetone were thermostated at 40.0 °C. To each of five flasks containing 2.00 mL of ethyl iodide was pipetted 2.00 mL of the carboxylate salt solution. The flasks were periodically removed, quenched, and titrated over a range of times exceeding 3 half-lives. The rate constants were determined by least squares analysis and the correlation coefficients were 0.997 or greater.

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The Absolute Configuration of (-)-Ethyl α-Formyl-α-methylphenylacetate and (-)-1,2-Diphenyl-2-methyl-1,3-propanedione
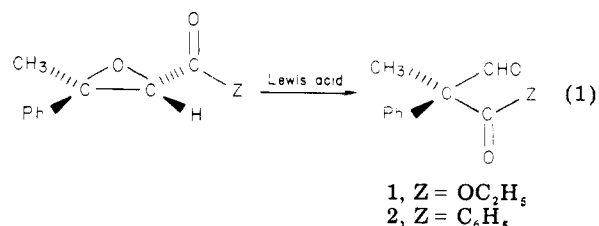
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The absolute configuration and optical purity of (-)-(S)-ethyl α-formyl-α-methylphenylacetate and (-)-S-1,2-diphenyl-2-methyl-1,3-propanedione have been established. The synthesis and resolution of α-methyltropic acid are described.

We have recently been engaged in a mechanistic investigation of 1,2-carbonyl migrations. In an effort to establish the degree of concertedness of these interesting transformations, we have utilized optically active substrates of known absolute configuration and optical purity. The Lewis acid catalyzed rearrangement of a series of glycidic esters,[2a] epoxy ketones,[2b] and chlorohydrins[2c] has provided experimental evidence that 1,2-carbonyl migration is concerted and proceeds with inversion of configuration at the migration terminus without loss of optical activity (eq 1). These stereochemical studies have re-

1, Z = OC_2H_5
2, Z = C_6H_5

quired us to determine the optical purity and absolute configuration of (-)-ethyl α-formyl-α-methylphenylacetate (1) and (-)-1,2-diphenyl-2-methyl-1,3-propanedione (2). In

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(2) (a) Domagala, J. M.; Bach, R. D.; Wemple, J. *J. Am. Chem. Soc.*, 1976, *98*, 1975; (b) Domagala, J. M.; Bach, R. D. *ibid*, 1978, *100*, 1605; (c) Domagala, J. M.; Bach, R. D. *ibid*. submitted for publication.