2b (Ar = 2,4-dinitrophenyl) anion, 86162-78-9; **2b** (Ar = 2,4,6-trinitrophenyl) anion, 86162-79-0; **2c** (Ar = 4-nitrophenyl), 86162-68-7; **2c** (Ar = 2,4-dinitrophenyl), 86162-69-8; **2c** (Ar = 2,4,6-trinitrophenyl), 86162-70-1; **2c** (Ar = 4-nitrophenyl) anion, 86162-80-3; **2c** (Ar = 2,4-dinitrophenyl) anion, 86162-81-4; **2c** (Ar = 2,4,6-trinitrophenyl) anion, 86162-82-5; **2d** (Ar = 4-nitrophenyl), 86162-71-2; **2d** (Ar = 2,4-dinitrophenyl), 86162-72-3; **2d** (Ar = 3,4,5-trimethoxyphenyl), 86162-73-4; **2d** (Ar = 4-nitrophenyl) anion, 86162-83-6; **2d** (Ar = 2,4-dinitrophenyl) anion, 86162-84-7; **2d** (Ar = 3,4,5-trimethoxyphenyl) anion, 86162-85-8; **3d** (Ar = 4-nitrophenyl), 86162-86-9; **3d** (Ar = 2,4-dinitrophenyl), 86162-87-0; **3d** (Ar = 3,4,5-trimethoxyphenyl), 86162-88-1; **4** (Ar = 4-nitrophenyl), 86162-91-6; **4** (Ar = 3,4,5-trimethoxyphenyl), 86162-92-7; **7a**, 86162-93-8; **7b**, 86162-94-9; **8a** (Ar = 3,4,5-trimethoxyphenyl), 86162-97-2; **8b** (Ar = 4-nitrophenyl), 86162-95-0; **8b** (Ar = 3,4,5-trimthoxyphenyl), 86162-96-1; **9**, 86162-98-3; *N*,*N*-dimethyl(2-nitrophenyl)acetamide, 76016-34-7; (2-nitrophenyl)acetic acid, 3740-52-1; (2-nitrophenyl)acetyl chloride, 22751-23-1; dimethylamine, 124-40-3; (2-nitrophenyl)acetonitrile, 610-66-2; (2-nitrophenyl)acetamide, 31142-60-6; dimethyl (2-nitrophenyl)malonate, 26465-37-2; dimethyl malonate, 108-59-8; 2-fluoronitrobenzene, 1493-27-2; methyl (2-nitrophenyl)acetate, 30095-98-8; *N*,*N*-dimethyl(2-aminophenyl)acetamide, 86162-60-9; (2-aminophenyl)acetonitrile, 2973-50-4; methyl (2-aminophenyl)acetate, 35613-44-6; dimethyl (2-aminophenyl)malonate, 86162-61-0; 4-nitrobenzaldehyde, 555-16-8; 2,4-dinitrobenzaldehyde, 528-75-6; 2,4,6-trinitrobenzaldehyde, 606-34-8; 3,4,5-trimethoxybenzaldehyde, 86-81-7; dimethyl (2,6-dinitrophenyl)-malonate, 86162-89-2; 2,6-dinitrochlorobenzene, 606-21-3; methyl (2,6-dinitrophenyl)acetate, 86162-90-5; (2,6-dinitrophenyl)acetic acid, 37777-63-2; 4-aminooxindole, 54523-76-1; *p*-toluenesulfonyl chloride, 98-59-9; *p*-toluyl chloride, 874-60-2.

Dimerization of Cyclopropanecarboxylic Acid Dianion and Thermal Decarboxylative Rearrangement of the Dimer to 2-Cyclopropyl-4,5-dihydrofuran

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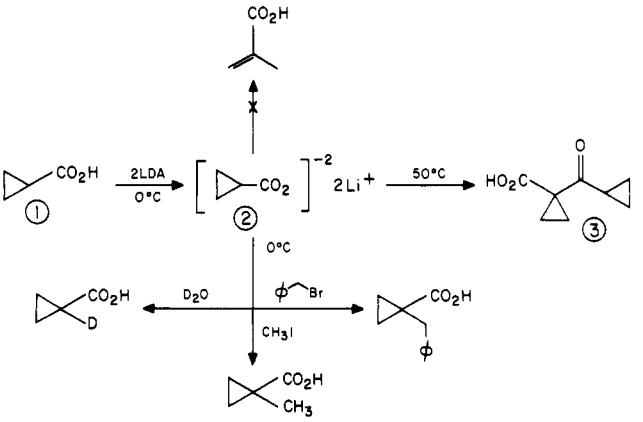
Received November 16, 1982

The dianion of cyclopropanecarboxylic acid (**2**) reacted with alkyl halides and deuterated water at temperatures below 0 °C; however, self-condensation to the β-keto acid **3** was the only observed product at elevated temperatures. This observation contrasts the self-condensation of the ethyl ester where a trimeric diester alcohol is the product. Attempted mixed condensations of the dianion **2** and carboxylic acids without acidic α-protons did not proceed as well, **3** being the major product. Thermal decarboxylation of **3** did not yield the expected dicyclopropyl ketone; rather, a facile rearrangement in a sealed tube at 120 °C occurred, giving rise to 2-cyclopropyl-4,5-dihydrofuran. This "vinyl–cyclopropyl" type rearrangement does not occur through dicyclopropyl ketone or its enolate.

Previous reports have demonstrated that the dianions of carboxylic acids undergo nucleophilic attack at electron-deficient centers.[1] These centers include alkyl halides[2] and the carbonyl carbons of aldehydes, ketones, esters, and acid chlorides.[3,4] An exception we reported previously was cyclopropanecarboxylic acid.[5] Upon dianion formation at 50 °C, followed by treatment with an electrophilic trapping agent, the only observed product appeared to be a dimer of the cyclopropanecarboxylic acid. This dimerization was in apparent conflict with experiments already completed by Ainsworth[6] and Ford[7] that demonstrated the incorporation of trimethylsilyl and deuterium, respectively, into the α-position of cyclopropanecarboxylates, using lithium diisopropyl amide (LDA) as a hindered base in THF. Concurrent with our own investigations, work by Pinnick[8] and Warner[9] have shed light on this "anomalous" reaction of the dianion of cyclopropanecarboxylic acid, and this has prompted us to report our work on the facile rearrangement of the dimeric product into 2-substituted 4,5-dihydrofurans.

The α-proton of a substituted cyclopropane may be rendered acidic by the attachment of a heteroatom such as phosphorus[10] or sulfur,[11] and in the ylide form, these substituted cyclopropyl anions act as good nucleophiles, attacking ketones and alkyl halides. The attachment of a carboxylate function to a cyclopropane ring should also cause the α-proton to be labile, and by analogy to our previous reports[3] on the formation of β-hydroxy acids from

Scheme I



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(6) (a) Ainsworth, C.; Cheir, F.; Kuo, Y.-N. *J. Organomet. Chem.* **1972**, *46*, 59. (b) Ainsworth, C.; Cheir, F.; Kuo, Y.-N. *Ibid.* **1973**, *47*, 73.

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Table I. Reaction of Lithium α-Lithiocyclopropanecarboxylate with Electrophiles

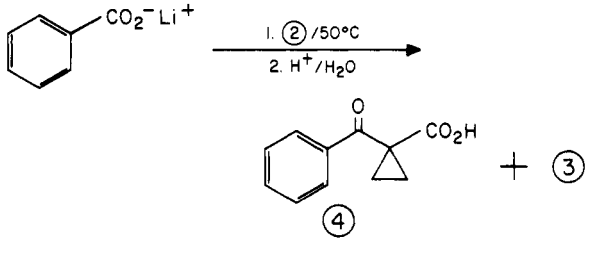
electrophile[a]	recovered 1, %	dimer 3, %	product (%)
benzoic acid	14	42	4 (18)
adamantane-carboxylic acid	33	44	(12)[b]
1-methylcyclopropane-carboxylic acid	25	54	(8)[b]
1-phenylcyclopropane-carboxylic acid	28	62	

[a] Used as lithium salts. [b] Yields were determined by NMR.

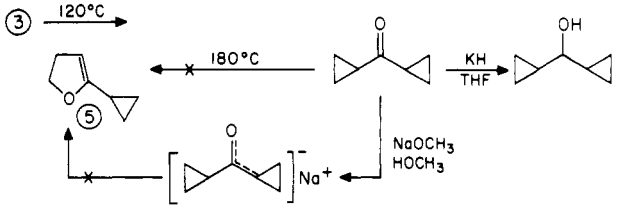
the condensation of the α-anion of cyclobutanecarboxylic acid with an appropriate ketone, we expected a similar finding with the dianion of cyclopropanecarboxylic acid. Contrary to our expectations, we observed that treatment of cyclopropanecarboxylic acid with 2 equiv of LDA in THF at −78 °C, heating to 50 °C for 1 h, followed by cooling to 0 °C and quenching with either D_2O, CH_3I, benzyl bromide, or cyclohexanone, followed by acidification, led to what appeared to be a self-condensation product. Indeed, leaving out the electrophile gave identical results, indicating that the product was formed prior to the addition of electrophile. It appeared likely that self-condensation occurred through dianion **2**; therefore, we repeated the experiment but did not allow the reaction to rise above 0 °C. Quenching with D_2O gave, in our hands, approximately 62% deuterium incorporation into the α-position of **1**, thus demonstrating trapping of the dianion of the acid (Scheme I). This is consistent with the results reported by Warner.[9]

Spectral examination of this self-condensation product demonstrated that no ring opening occurred as in the case of *cis,trans*-2,3-diphenylcyclopropane-1-carboxylic acid.[7] A product of this type would show a vinylic proton peak in the ^1H NMR spectrum. Infrared spectroscopy indicated that the product was a β-keto acid, and ^1H NMR showed the two cyclopropyl rings intact. The product was esterified with diazomethane in ether to give the methyl ester and reacted, albeit slowly, with Br_2 in CCl_4 and 2,4-dinitrophenylhydrazine. Mass spectroscopy and elemental analysis were consistent with structure **3** (Scheme I).

Reaction of **2** with other carboxylate salts at room temperature gave no products from cross-condensation. Raising the temperature to 50 °C, however, gave rise to both the dimer **3** and in the case of benzoic acid a new β-keto acid containing both aromatic and cyclopropyl functions (**4**). Adamantanoic acid, 1-phenyl-1-cyclopropanecarboxylic acid, and 1-methyl-1-cyclopropane-carboxylic acid gave only recovered starting material and dimer **3**, with small amounts of a new product formed (Table I).



Scheme II



With the β-keto acids in hand, we set out to form the appropriate ketones by thermal decarboxylation to known compounds. We decarboxylated the isolated **3** neat, in sealed tubes, at 120 °C. Using a gas IR cell, we demonstrated that the dimer clearly evolved CO_2, yielding an oil upon isolation. Rather than the expected dicyclopropyl ketone, the isolated product exhibited a significantly altered ^1H NMR spectrum, showing a single monosubstituted cyclopropyl ring intact (multiplet, 1.0, 4 H) and a single proton triplet at δ 4.26. The ^1H NMR spectrum and the mass spectral fragmentation pattern are consistent with the dimer undergoing decarboxylation and a thermal "vinyl–cyclopropyl" type rearrangement to give 2-cyclopropyl-4,5-dihydrofuran (**5**) and no evidence for dicyclopropyl ketone (Scheme II).

Under the same conditions or even at 180 °C, dicyclopropyl ketone did not undergo rearrangement and gave only trace amounts of decomposition. This is not surprising in view of the fact that temperatures of 300–400 °C[12] or transition-metal catalysts[13] are usually employed to effect the vinyl–cyclopropyl rearrangement. In light of a recent finding that lithium alkoxides of vinylcyclopropanols greatly accelerated the vinyl–cyclopropane rearrangement,[14] allowing formation of 3-cyclopentenols at room temperature, we postulated that intervention of the enolate or enol of dicyclopropyl ketone following the thermal decarboxylation of dimer **3** could be responsible for our facile rearrangement. Attempted enolization of dicyclopropyl ketone by LiH or NaH in THF, followed by quenching with D_2O, led only to the recovery of starting material. Turning to the more reactive KH in THF, we observed no evolution of H_2 and after 4 h at room temperature isolated dicyclopropyl carbinol in good yield. To circumvent this unusual, however, not unknown, reduction,[15] dicyclopropyl ketone was enolized as previously reported,[16] and heated in a manner identical with the thermal decarboxylation reaction described above. Acidification with DCl gave 83% incorporation of deuterium into dicyclopropyl ketone by NMR and no evidence of dihydrofuran formation. Experimentally we could not obtain evidence for the intermediacy of dicyclopropyl ketone during the rearrangement.

Discussion

In the report by Pinnick[8] using ethyl cyclopropanecarboxylate, trimer **6** is formed after 1 h of reaction at room temperature with LDA. It is of interest to note that in our

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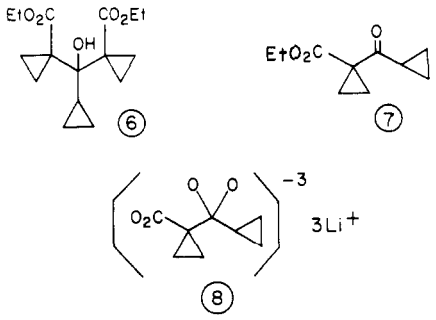
(16) v. Wijnen, W. T.; Steinberg, H.; deBoer, T. J. *Recl. Trav. Chim. Pays-Bas* **1968**, *87*, 844.



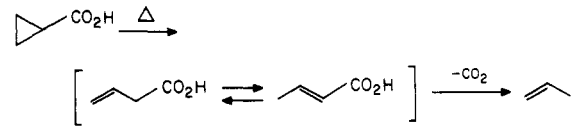
case the dianion of cyclopropanecarboxylic acid survives forcing conditions (50 °C for 1 h) and terminates at dimer **3**. This is reasonable in light of the intermediates formed from these similar reactions. In the case of the ester, a nucleophilic attack followed by loss of ethoxide leaves the reactive β-keto ester **7** intact and susceptible to further alkylation. On the other hand, attack of the dianion **2** on the acid function of another molecule of **2** yields the intermediate trianion **8**, which precludes further attack.[17] The presence of the trianion renders the acid carboxylate moiety less prone to attack due to charge repulsion and increased activation energy.

Earlier we reported significantly greater dianion formation from α,α-disubstituted carboxylic acids by heating to 50 °C.[1] This heating apparently overcomes the barrier to the formation of the delocalized trisubstituted anion that is not observed in the monosubstituted case where complete dianion formation does occur at lower temperatures. While our work and the work of others has demonstrated that the dianion cyclopropanecarboxylic acid forms at room temperature with LDA and reacts readily with electrophiles such as alkyl halides and trimethylsilyl chloride but sparingly with carboxylic centers such as CO_2 and the acid salts mentioned in Table I, it does appear that dianion **2** will readily self-condense at elevated temperatures. These results are fully consistent with the work reported by Warner.[9] We did not study the reaction using esters as electrophiles since the initial product of attack, a keto acid, would be susceptible to further in situ attack, yielding analogues of trimeric compound **6**.

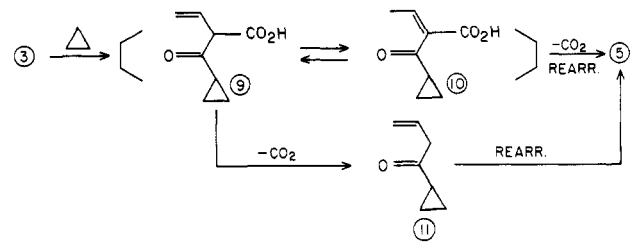
The formation of the dimer at elevated temperatures may also explain Warner's negative results when he attempted to decarboxylate the dianion at 80 °C in the reaction medium in an attempt to obtain the intriguing 1,1-dilithiocyclopropane.[9] We would predict that under these conditions, and certainly prior to decarboxylation, the dianion **2** would yield the dimer **3**.

The thermal decarboxylation of dimer **3**, however, did not lead to the expected dicyclopropyl ketone. Rather, it yielded 2-cyclopropyl-4,5-dihydrofuran through a thermal rearrangement. The ease at which this rearrangement occurs makes us suspect of a simple thermal vinyl–cyclopropane rearrangement. Examination of the literature reaction conditions[18] and Dreiding models suggests that a formal (1,3) sigmatropic shift of either the dimer **3** or the decarboxylated material (dicyclopropyl ketone) is quite

Scheme III

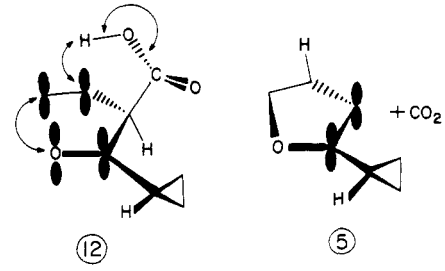


Scheme IV



unlikely. Our experimental results seem to indicate that a dicyclopropyl ketone or its anion is not involved. It has been shown in the case of cyclopropanecarboxylic acid that thermal decarboxylation leads initially to either the 2,3- or 3,4-unsaturated butenoic acid through 1,3-cyclopropyl bond cleavage, followed by decarboxylation to yield propene[18] (Scheme III). This ring opening is especially favorable if the transient 1,3-diradical is stabilized by a substituent in the 3-position.[19] It is therefore possible that the rearrangement of dimer **3** may proceed through an initial cyclopropyl ring opening. In the case of dimer **3**, even though there is no substituent stabilization of a radical in the β-position, the 1,3-cyclopropyl bond is significantly weakened by the presence in the 1-position of both a carboxylic and carbonyl function. Initial 1,3-bond cleavage may explain the ease of decarboxylation and rearrangement of dimer **3** as compared to the thermal decarboxylation of cyclopropanecarboxylic acid (140 °C for 4 h for dimer **3**, vs. 360 °C for 15 h for cyclopropanecarboxylic acid).

We propose the following mechanism to explain our facile decarboxylation and keto–cyclopropyl rearrangement of dimer **3**. Following 1,3-cyclopropyl bond cleavage, there is a rapid (1,2) H shift from the 2-position to either the 1 or 3 carbon, yielding **9** and/or **10**. These products may be in rapid thermal equilibrium through (1,3) H shifts.[18] As suggested for cyclopropanecarboxylic acid, decarboxylation would occur through the β,γ-unsaturated intermediate **9**, which could then directly lead to **5** by a synchronous loss of CO_2 and collapse of the system in a pericyclic process, or by analogy to cyclopropanecarboxylic acid, **9** could stepwise decarboxylate to allylcyclopropyl ketone and thermally rearrange to **5**. These possibilities are shown in Scheme IV. Examination of Dreiding models leads us to favor a concerted process occurring after initial formation of **9**, due to the proximity of the olefinic and carbonyl moieties and the possibility of positioning the OH proton of the carboxyl function directly over the olefin π-system as represented in **12**. The concerted process



(17) It was suggested by one of the referees that the dimerization could occur due to the presence of trace amounts of water in the cyclopropanecarboxlic acid or the reaction mixture, which would quench some of the dianion. We have run the reaction with up to 10 equiv of LDA and obtained the same results. However, it is still possible that while being heated to 50 °C, the dianion, **2**, attacks the lithiocyclopropanecarboxylate that has either not formed dianion **2** or is in equilibrium with diisopropylamine/LDA. Pfeffer has previously shown that removal of diisopropylamine to shift the equilibrium only slightly enhances the formation of the α-anion of carboxylic acids: Pfeffer, P. E.; Silbert, L. S.; Chirinko, J. M. *J. Org. Chem.* **1972**, *37*, 451.

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(19) McGreer, D. E.; McKinley, J. W. *Can. J. Chem.* **1973**, *51*, 1487.

would also explain why we observed no allyl cyclopropyl ketone **11** from direct decarboxylation of either **9** or **10**. Currently we are pursuing the synthesis of the proposed intermediates in order to directly implicate the ring-opened intermediate and shed light on whether the rearrangement is synchronous or stepwise.

Experimental Section

Melting points were determined on a Thomas-Hoover apparatus and were uncorrected. All reactions involving LDA or KH were run under argon in glassware that was flamed out. Tetrahydrofuran was distilled from sodium, benzophenone being used as an indicator. Cyclopropanecarboxylic acid was dried over molecular sieves and distilled prior to use. Microanalysis was performed by Galbraith Labs. Infrared spectra were obtained on a Beckman Model 5240 spectrophotometer. Proton NMR spectra were determined on Varian T-60 and EM-360 spectrometers. Mass spectra were determined on a Hewlett-Packard Model 5985-B GC–MS.

Preparation of Lithium α-Lithiocyclopropanecarboxylate (2). A 100-mL three-necked flask was fitted with a magnetic stirrer, serum cap, argon inlet, and addition funnel containing 10 mmol of cyclopropanecarboxylic acid (0.86 g) in 5 mL of dry THF. The flask was charged with 25 mL of dry THF and 20 mmol (2.04 g) of diisopropylamine and cooled to −20 °C. To the magnetically stirred solution was injected 20 mmol (12.5 mL of 1.6 M in hexane) of *n*-BuLi, and the resulting LDA solution then stirred an additional 30 min. Cyclopropanecarboxylic acid was then added dropwise over 10 min at −20 °C and the reaction stirred an additional 10 min before thermal dimerization or the addition of electrophiles.

Preparation of 1-(Cyclopropylcarbonyl)cyclopropanecarboxylic Acid (3). A solution of 10 mmol of **2** was heated to 50 °C for 2 h and cooled to room temperature. (In the initial studies, 10 mmol of cyclohexane, methyl iodide, or D_2O was added at this point.) The pale yellow solution was then poured over 50 mL of ice acidified with HCl and extracted with 4 × 25 mL of ether. The organic phase was dried over $MgSO_4$, the solvent removed by rotoevaporation, and the semisolid mass (0.59 g, 76%) recrystallized from ether–pentane (2:1) at 4 °C, yielding 0.48 g (62%) of a solid (mp 85–87 °C). The oil recovered from the filtrate gave 0.32 g (38%) of starting material **3**: IR (CCl_4) 3400–2450 (br), 1690, 1440, 1230, 925 cm^{-1}; ^1H NMR ($CDCl_3$) δ 12.7 (br 1 H), 2.2–1.8 (m, 4 H), 1.7–1.0 (m, 5 H); mass spectrum, *m/e* 154, 126, 113, 95, 69, 41, 39. Anal. Calcd for $C_8H_{10}O_3$: C, 62.34; H, 6.49. Found: C, 62.62; H, 6.53.

Preparation of 1-Methylcyclopropanecarboxylic Acid. To a solution of 10 mmol of **2** at −20 °C was added dropwise 20 mmol (2.8 g) of CH_3I in 5 mL of THF, and after removal of the bath, the mixture was stirred an additional 1 h while being warmed to room temperature. The reaction mixture was worked up as described above, yielding 0.9 g of an oil. ^1H NMR confirmed that the reaction mixture was 32% 1-methylcyclopropanecarboxylic acid and 68% starting material. Further confirmation was obtained from VPC (10% FFAP, Chromosorb W), which gave a 3:7 ratio of material with identical retention time with an authentic sample from Aldrich and starting material. No other products were observed.

Preparation of 1-Benzylcyclopropanecarboxylic Acid. To a solution of 10 mmol of **2** was added 20 mmol (3.4 g) of benzyl bromide in 5 mL of THF at −20 °C. The cooling bath was removed and the reaction mixture allowed to warm to room temperature with stirring for an additional hour. The reaction was worked up as described above, yielding a solid that upon recrystallization from pentane gave 0.39 g (22%) of a crystalline solid: mp 101–104 °C; IR (CCl_4) 3450–2400, 1710, 1610, 1500, 1430, 1225 cm^{-1}; ^1H NMR ($CDCl_3$) δ 12.3 (s, 1 H), 7.3 (s, 5 H), 3.0 (s, 2 H), 1.5–0.9 (A_2B_2, 4 H); mass spectrum, *m/e* 176, 148, 132, 91, 77. Anal. Calcd for $C_{11}H_{12}O_2$: C, 74.96; H, 6.81. Found: C, 74.91; H, 7.10.

Preparation of 1,1-Cyclopropanedicarboxylic Acid. To a solution of 10 mmol of **2** at −20 °C was added a steady stream of dried CO_2. The reaction was allowed to warm to room temperature over 1 h. The standard workup was performed, and a solid mass was obtained from pentane. Recrystallization from a pentane–ether mix (4:1) gave a solid (0.72 g) containing starting material (78%) and a new product (22%) corresponding in ^1H NMR to authentic 1,1-cyclopropane dicarboxylic acid obtained from Aldrich Chemical Co.

Preparation of Methyl 1-(Cyclopropylcarbonyl)cyclopropanecarboxylate. The cyclopropanecarboxylic acid dimer (0.5 g, 3 mmol) was dissolved in 20 mL of ether, and to this stirred solution was added diazomethane (~0.05 M) in ether until a persistent yellow color was obtained. The solvent was evaporated in vacuo. The residual oil was redissolved in $ChCl_3$, dried with $MgSO_4$, and evaporated. Molecular distillation of this oil (pot temperature, 85 °C) under vacuum (21 mmHg) afforded 0.42 g (82.8%) of the ester: IR (neat) 3150, 3050–2900, 1725, 1690, 1450, 1385, 1325, 1200, 1160, 1060, cm^{-1}; ^1H NMR ($CDCl_3$) δ 3.6 (s, 3 H), 2.6–2.2 (m, 1 H), 1.4 (s, 4 H); mass spectrum, *m/e* 168, 140, 127, 113, 109, 99, 55. Anal. Calcd for $C_9H_{12}O_3$: C, 64.28; H, 7.14. Found: C, 64.73; H, 6.82.

$NaBH_4$ Reduction of 1-(Cyclopropylcarbonyl)cyclopropanecarboxylic Acid. To a solution of 0.76 g (5 mmol) of dimer **3** in 15 mL of dry propanol was added 0.75 (20 mmol) of sodium borohydride over 20 min, keeping the reaction temperature below 30 °C. The mixture was stirred an additional 2 h at room temperature, after which the milky white suspension was cooled to 4 °C, acidified with 3 N HCl, and diluted with 50 mL of water. The aqueous solution was extracted with 3 × 25 mL of ether, the combined organic phases were dried with $MgSO_4$, and the solvent was removed by rotoevaporation. The residual oil (0.71 g, 90.4%) would not crystallize and decomposed upon attempted distillation: IR (neat) 3700–3300 (br), 1690, 1425, 1250, 1175, 1025 cm^{-1}; ^1H NMR ($CDCl_3$) δ 6.5 (s, 2 H, OH and C(O)), 3.0 (d, 1 H), 1.5–1.0 (m, 5 H), 0.65–0.25 (m, 4 H). Anal. Calcd for $C_8H_{12}O_3$: C, 61.54; H, 7.69. Found: C, 61.62; H, 7.27.

General Method for 1-Acylcyclopropanecarboxylic Acids. A solution of 10 mmol (0.86 g) of cyclopropanecarboxylic acid in 25 mL of dry THF and 30 mmol (3.06 g) of lithium diisopropylamide wa s held at −20 °C, and a solution of the carboxylic acid in 5 mL of THF was added slowly. The reaction was then heated to 50 °C for 2 h, and workup was done as previously described.

Cyclopropanecarboxylic Acid plus Benzoic Acid (4). The product was recrystallized from ether–acetone (4:1), yielding 0.68 g (35.8%) of a solid that was a 50% mix of dimer **3** and 1-benzoylcyclopropanecarboxylic acid (overall yield 18%). Further fractional crystallizations gave a sample (mp 146–152 °C), while the residue contained unreacted acids and dimer **3**. **4**: IR (CCl_4) 3400–2500, 1695, 1600, 1455, 1425, 1330, 1275, 1010 cm^{-1}; ^1H NMR ($CDCl_3$) δ 12.8 (s, 1 H), 7.9 (m, 2 H), 7.6 (m, 3 H), 1.6 (A_2B_2, 4 H). Anal. Calcd for $C_{11}H_{10}O_3$: C, 69.47; H, 5.26. Found: C, 69.73; H, 5.61.

1-Adamantanecarboxylic Acid plus Cyclopropanecarboxylic Acid. The product after normal workup gave 1.8 g of a semisolid mass (72%). This contained a 4:1 ratio of dimer **3** and 1-(acyladamantyl)cyclopropanecarboxylic acid (12% overall yield). An analytical sample was obtained by fractional recrystallization: mp 80–83%; IR (CCl_4) 3450–2450, 1700, 1550, 1420, 1390, 1225, 1010 cm^{-1}; ^1H NMR ($CDCl_3$) δ 12.4 (s, 1 H), 2.0–1.7 (m, 15 H), 1.3–0.9 (m, 4 H). Anal. Calcd for $C_{15}H_{20}O_3$: C, 72.58; H, 8.06. Found: C, 72.68; H, 8.41.

1-Methylcyclopropanecarboxylic Acid plus Cyclopropanecarboxylic Acid. After standard workup, 2.4 g of an oil was isolated. Repeated attempts at purification by recrystallization or distillation failed to give a product free of dimer **3**. The NMR yield was 54% of dimer **3** and 8% of 1-(1-methylcyclopropylcarbonyl)cyclopropanecarboxylic acid.

1-Phenylcyclopropanecarboxylic Acid plus Cyclopropanecarboxylic Acid. The only isolated product of this reaction was 0.88 g (62%) of dimer **3**.

Decarboxylation of 3 and 5. The compounds were sealed in an evacuated tube and heated at 120 °C for 2.0 h. During the heating period evolution of a gas was noted. Upon cooling, the tubes were opened and the residual oils washed out with ether.

2-Cyclopropyl-4,5-dihydrofuran (5). The oil from the sealed tube gave 1.47 g (96%), which was fractionated by molecular distillation at 0.4 mmHg. At a pot temperature of 80 °C, a fraction (0.13 g) was collected. NMR, IR, and VPC analyses confirm this to be dicyclopropyl ketone when compared to an authentic sample (Aldrich). The yield of dicyclopropyl ketone is 6.5%. Raising

the pot temperature to 125 °C gave the major fraction (1.02 g) as a clear oil identified as 2-cyclopropyl-4,5-dihydrofuran **5** (72%): IR (neat) 3020, 2990, 1450, 1400, 1320, 1075 cm^{-1}; ^1H NMR ($CDCl_3$) δ 4.26 (t, 1 H), 2.65 (m, 2 H), 2.05 (m, 2 H), 1.45 (m, 1 H), 1.0 (m, 4 H); mass spectrum, *m/e* 110, 95, 82, 69, 55, 41. Anal. Calcd for $C_7H_{10}O$: C, 76.36; H, 9.09. Found: C, 76.44; H, 9.34.

2-Phenyl-4,5-dihydrofuran. The oil from the sealed tube (0.70 g) gave a mixture containing both phenyl cyclopropyl ketone and 2-phenyl-4,5-dihydrofuran. Distillation could not fully separate the products; however, yields by NMR indicated the material contained 420 mg (78%) of phenylcyclopropyl ketone and 58 mg (8.3%) of 2-phenyl-4,5-dihydrofuran.

Reaction of Dicyclopropyl Ketone with KH. Formation of Dicyclopropylcarbinol. To a suspension of 8 mL (90 mmol) of KH (21% in oil) in 25 mL of dry THF (oil was removed by three repeated decantations from 25 mL of THF) was added 5 g (45 mmol) of dicyclopropyl ketone in 5 mL of THF. The mixture was stirred at room temperature for 14 h, during which time no evolution of gas was noted. Workup consisted of slow addition at 0 °C of 10 mL of 5% HCl (again only a limited evolution of gas), followed by extraction with 3 × 25 mL of ether. The combined organic phases were dried over $MgSO_4$, and the solvent was evaporated. The dark oil was distilled (pot temperature 80 °C), yielding 3.8 g (76%) of dicyclopropylcarbinol and 0.8 g (16%) of the starting ketone. The carbinol was identical with an authentic sample from Aldrich.

$NaBH_4$ Reduction of Dicyclopropyl Ketone. A solution of 1.12 g (1.01 mol) of dicyclopropyl ketone in 20 mL of ethanol, dried by distillation from Mg^0, was cooled to 4 °C. Sodium borohydride (1.2 g, 0.03 mol) was added slowly, dipping the temperature below 30 °C, and the mixture was stirred an additional hour. After the solution was cooled in an ice bath for 10 min, water was added followed by 10 mL of 2 N HCl. The reaction was then boiled for 5 min, cooled, and extracted with 3 × 25 mL of ether. The organic phases were combined and dried with $MgSO_4$, and the solvent was evaporated. A 70% yield (0.78 g) of a clear oil was obtained, identical with the above dicyclopropylcarbinol.

Reaction of Dicyclopropyl Ketone with Sodium Methoxide. A solution of 1.12 g (1.01 mol) of dicyclopropyl ketone in 20 mL of CH_3OD containing 0.05 mol of sodium methoxide (previously prepared from Na^0) was stirred at room temperature for 14 h. The reaction was diluted with 50 mL of D_2O and extracted with 3 × 25 mL of ether. The organic phases were combined, dried with $MgSO_4$, and evaporated. The resulting oil had a ^1H NMR spectrum that showed 63% incorporation of deuterium in the α-position to the ketone (δ 2.2).

Acknowledgment. E.G.E.J. thanks Alan J. Lovey, Berhanu Abegaz, and James J. Bohning for their helpful discussions and continued support.

Registry No. 1, 1759-53-1; 2, 80375-26-4; 3, 86101-65-7; 4, 79172-43-3; 5, 67219-43-6; $PhCH_2Br$, 100-39-0; CH_3I, 74-88-4; 1-methylcyclopropanecarboxylic acid, 6914-76-7; 1-benzylcyclopropanecarboxylic acid, 27356-91-8; 1,1-cyclopropanedicarboxylic acid, 598-10-7; methyl 1-(cyclopropylcarboxyl)cyclopropanecarboxylate, 86101-66-8; dicyclopropylcarbinol, 14300-33-5; 1-(adamant-1-ylcarbonyl)cyclopropanecarboxylic acid, 86101-67-9; 1-(1-methylcyclopropylcarbonyl)cyclopropanecarboxylic acid, 86101-68-0; 2-phenyl-4,5-dihydrofuran, 17851-50-2; dicyclopropyl ketone, 1121-37-5; lithium benzoate, 553-54-8; lithium 1-adamantanecarboxylate, 86101-69-1; lithium 1-methylcyclopropanecarboxylate, 86101-70-4; 1-(α-cyclopropyl-α-hydroxymethyl)cyclopropanecarboxylic acid, 72436-82-9.

Facile Syntheses of Fluorescent Heterocycles from N-Methylated Vitamin B_1

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Received September 23, 1982

1'-Methylthiaminium ion reacts with 2-amino- and substituted 2-aminopyridines in methanol by substitution–cyclization steps to give derivatives of pyrichromine. Similarly, 2-aminothiazole forms a thiochromine. All these tricyclic products show brilliant fluorescence under ordinary light. The quantum yield of a pyrichromine in aqueous solution at room temperature is 0.8. The thiamin also reacts with thiourea to yield a fluorescent fused bicyclic product. Structures were proven by magnetic resonance studies.

Fluorescent compounds which efficiently emit light have found many applications. For example, those fluorophores whose emissions are sensitive to environment are used as bioprobes (reporter molecules) to provide information about local solvent polarity, conformations, and dynamics within regions of macromolecules.[1,2] Moreover, intersite distances within large molecules can be measured by using the efficiency of energy transfer between a fluorescent donor and an acceptor as a "spectroscopic ruler".[3] By contrast, environmentally insensitive fluorophores are prepared as derivatives to enhance detection limits, often markedly, in quantitative analysis.[4]

We report a simple synthesis of fluorescent heterocyclic compounds. Our method which is capable of being extended[5,6] uses a vitamin B_1 derivative, 1'-methylthiaminium ion[7] (**1**, $C_6H_9N_3{}^+CH_2L$), as the principal reactant (Chart I).

Results and Discussion

Syntheses. Heating a methanolic mixture of **1** and 2-aminopyridine (**2**) at reflux gives rise to a fluorescent product. Elemental and spectroscopic analyses show that

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0022-3263/83/1948-2476$01.50/0