1600, 1375 and 1180 cm^{-1} (tosyl).

Homopolymer 7dp. **7p** (290 mg) was treated with 20 mL of 0.5 M aqueous NaOH for two days at 40 °C. The reddish-brown solution was submitted to ultrafiltration (Diaflo-Ultrafilter UM-2) and freeze-dried. The polymer was obtained as a brown spongy solid: yield 164 mg (60%) of **7dp**; $[\alpha]^{20}_D$ −63° (*c* 0.2, Tris buffer); $[\eta]$ 0.15 dL/g (Tris buffer, 30.00 °C). Anal. Calcd for $C_7H_9N_2O_4Na(H_2O)_{0.72}$: C, 37.8; H, 5.0; N, 12.7; O, 34.1; Na, 10.4. Found: C, 37.8; H, 5.0; N, 12.7; O, 34.2; Na, 10.3. IR (KBr) 3700–3200 (NH, OH, and H_2O), 1650 cm^{-1} (NHCO). The vibration of the azomethine (C=N) group is masked by NHCO and COO^- vibrations. This is also the case for the other deprotected polymers. Variations in the deprotection reaction time gave polymer samples with identical physical properties.

Homopolymer 8dp. **8p** (250 mg) was deprotected as described for **7dp**. The polymer was obtained as a dark-brown powder: yield 243 mg (100%) of **8dp**; $[\alpha]^{20}_D$ −57° (*c* 0.2 Tris buffer). Anal. Calcd for $C_7H_9N_2O_4Na(H_2O)_{1.5}(C_2H_2O)_{0.15}$: C, 36.3; H, 5.2; N, 11.7; O, 37.4; Na, 9.5. Found: C, 36.4; H, 5.4; N, 11.9; O, 36.8; Na, 9.5. Ir (KBr) data as for **7dp** within 5 cm^{-1} and in addition 1720 cm^{-1} ($COOCH_3$).

Homopolymer 9dp. This polymer was deprotected as described previously.[10]

Copolymer 10dp. **10p** (580 mg) was detosylated by dissolving this polymer in 30 mL of acetic anhydride–pyridine, 1:1 v/v, and keeping this solution overnight at room temperature. After removal of the solvent in vacuum the residue was treated for two days with 20 mL of 0.5 M aqueous NaOH at 40 °C. The reddish-brown solution was acidified (pH 2.5), submitted to ultrafiltration (Diaflo Ultra-Filter UM-2), and freeze-dried. Polymer **10dp** was obtained as a reddish-brown powder: yield 412 mg (100%); $[\alpha]^{20}_D$ −43° (*c* 0.2 Tris buffer); $[\eta]$ 0.60 (Tris buffer, 30.00 °C). Anal. Calcd for $C_{24.7}H_{32.8}N_{8.3}O_{11.2}(HCl)_{0.3}(H_2O)_{0.5}$: C, 46.5; H, 5.2; N, 18.2; O, 28.1; Cl, 1.9. Found: C, 46.8; H, 5.4; N, 18.1; O, 27.9; Cl, 1.8 IR (KBr) data as for **8dp** within 5 cm^{-1} and in addition 2800–2200 cm^{-1} (HCl).

Copolymer 11dp. **11p** (315 mg) was treated as described for **10dp** except that for the hydrolysis 0.5 M aqueous KOH was used. Polymer **11dp** was obtained as a voluminous, spongy, yellowish-brown solid: yield 190 mg (85%); $[\alpha]^{20}_D$ −130° (*c* 0.2, Tris buffer); $[\eta]$ 0.42 dL/g (Tris buffer 30.00 °C). Anal. Calcd for $C_{15.4}H_{20.1}N_{5.2}O_{6.5}K_{0.2}(H_2O)_{1.3}$: C, 44.4; H, 5.4; N, 18.0; O, 30.0; K, 2.2. Found: C, 44.6; H, 5.2; N, 18.0; O, 30.1; K, 2.1. IR (KBr) data as for **8dp** within 5 cm^{-1}.

Copolymer 12dp. **12p** (256 mg) was treated as described for **11dp**. Polymer **12dp** was obtained as a reddish-brown powdery solid: yield 92 mg (50%); $[\alpha]^{20}_D$ −30° (*c* 0.2, Tris buffer); $[\eta]$ 0.55 dL/g (Tris buffer, 30.00 °C). Anal. Calcd for $C_{27.8}H_{34.1}N_{10.3}O_{10.2}K_{0.9}(H_2O)_{4.2}$: C, 42.5; H, 5.4; N, 18.3; O, 29.3; K, 4.5. Found: C, 42.7; H, 5.2; N, 18.2; O, 29.6; K, 4.3. IR (KBr) data as for **8dp** within 5 cm^{-1}.

Copolymer 13dp. **13p** (350 mg) was treated as described for **11dp**. Polymer **13dp** was obtained as a dark-brown powdery solid: yield 194 mg (66%); $[\alpha]^{20}_D$ −87° (*c* 0.2, Tris buffer); $[\eta]$ 0.20 dL/g (Tris buffer, 30.00 °C). Anal. Calcd for $C_{49.2}H_{72.1}N_{13.7}O_{14.5}K_{4.1}(H_2O)_{2.8}$: C, 45.5; H, 5.7; N, 13.9; O, 22.5; K, 12.4. Found: C, 45.3; H, 5.6; N, 13.8; O, 22.8; K, 12.5. IR (KBr) data as for **8dp** within 5 cm^{-1} and in addition 2920 cm^{-1} (CH).

Copolymer 14dp. **14p** (316 mg) was treated as described for **11dp**. Polymer **14dp** was obtained as a dark-brown powdery solid: yield 192 mg (99%); $[\alpha]^{20}_D$ −82° (*c* 0.2, Tris buffer); $[\eta]$ 0.08 dL/g (Tris buffer, 30.00 °C). Anal. Calcd for $C_{17.7}H_{22.1}N_{6.3}O_{3.2}K_{0.7}(H_2O)_{0.75}$: C, 44.2; H, 5.3; N, 18.3; O, 26.5; K, 5.7. Found: C, 44.3; H, 5.1; N, 18.3; O, 26.4; K, 5.9. IR (KBr) data as for **7dp** and **8dp** within 5 cm^{-1}.

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Registry No. **1**, 10512-86-4; **2a**, 5680-80-8; **2b**, 5874-57-7; **4a**, 97171-35-2; **4b**, 97171-36-3; **4c**, 75382-89-7; **5a**, 97171-40-9; **5b**, 97171-37-4; **5c**, 75345-20-9; **7p**, 97190-26-6; **8p**, 97171-38-5; **10p**, 97171-41-0; **13p**, 97233-23-3; **14p**, 97233-24-4; $NiCl_2$, 7718-54-9; acetic anhydride, 108-24-7.

Manganese(III) γ-Lactone Annulation with Substituted Acids

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Manganese(III) acetate oxidation of several $HOOCCH_2X$, X = electron withdrawing group, in the presence of alkenes led to the formation of α-substituted γ-lactones. Chloroacetic acid gave α-chloro γ-lactones, which were converted in two steps to the corresponding α,β-unsaturated γ-lactones. 3-Chloropropanoic acid led to the α-methylene γ-lactone after base induced elimination of HCl. Cyanoacetic acid produced α-cyano γ-lactones which could be hydrolytically decyanated or converted to the α-methylene γ-lactones in two steps. Potassium methyl malonate was oxidized and annulated onto alkenes to give α-carbomethoxy γ-lactones in reasonable yields. The method demonstrates a general route into several useful types of substituted γ-lactones.

The annulation of a γ-lactone ring onto an alkene by manganese(III) acetate, $[Mn_3O(OAc)_6(OAc)(HOAc)]\cdot 5H_2O$ = $[Mn_3O]$, according to eq 1 has been examined by us[2] and others.[3-6] In addition, limited studies of substituted acetic acid, XCH_2COOH, X = Me,[3a,b,7] CN,[3a] have been reported including the use of malonic acid to generate spiro dilactones.[8,9] Our interest in furthering the use of Mn(III) in organic synthesis, and the desirability of a simple, one-step route to α-substituted γ-lactones led us to investigate the Mn(III) oxidation of a number of acids. This paper outlines our results with chloroacetic, 3-chloropropanoic, cyanoacetic, and monomethyl malonic acid.

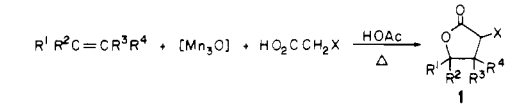

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Table I. Chloroacetic Acid Lactonization and Elimination to α,β-Unsaturated γ-Lactones

alkene	α-chloro γ-lactone, 1, X = Cl	yield, %[a]	stereochemistry (ratio)	elim method[b]	α,β-unsaturated γ-lactone, %
1-decene	$R_1 = C_8H_{17}$, R_2,R_3,R_4 = H	52	3α,5α,:3α,5β (1.25:1.0)	A	72[c]
trans-4-octene	$R_1,R_3 = C_3H_7$, R_2,R_4 = H	33	3α,4α,5α,:3α,4α,5β:3α,4β,5α:3α,4β,5β (1.0:7.3:6.3:2.0)	B	36[d]
cycloheptene	$R_1,R_3 = (CH_2)_5$, R_2,R_4 = H	41	3α,3aα,8aα:3α,3aα,8aβ:3α,3aβ,8aα:3α,3aβ,8aβ (1.2:1.1:1.0:1.5)	B	69[e]
cyclooctene	$R_1,R_3 = (CH_2)_6$, R_2,R_4 = H	53	3α,3aα,9aα:3α,3aα,9aβ:3α,3aβ,9aα:3α,3aβ,9aβ (1.0:7.3:6.3:2.0)	A	64
methyl cinnamate	R_1 = Ph, R_2,R_4 = H, $R_3 = CO_2Me$	35	3α,4β,5α		

[a] Isolated yield based on reacted alkene, typically 40%. [b] Method A consisted of conversion to the iodo lactone with NaI/acetone followed by refluxing with Et_3N/THF. Method B consisted of conversion to the iodo lactone with NaI/acetone followed by refluxing in neat Et_3N in the presence of Et_4NI. [c] This includes the β,γ-unsaturated isomer as well, α,β:β,γ = 1:2. [d] A 16% recovery of the iodo lactone was obtained. [e] A 4% recovery of the iodo lactone was obtained.

Table II. 3-Chloropropanoic Acid Lactonization and Elimination to α-Methylene γ-Lactones

alkene	α-chloromethyl lactone, 1, X = CH_2Cl	yield, %[a]	stereochemistry (ratio)	α-methylene γ-lactone, %	stereochemistry (ratio)
1-decene	$R_1 = C_8H_{17}$, R_2,R_3,R_4 = H	50	3α,5α,:3α,5β (1.5:1.0)	92	
trans-4-octene	$R_1,R_3 = C_3H_7$, R_2,R_4 = H	29	undetermined	90	4α,5α:4α,5β (1.0:2.7)
cycloheptene	$R_1,R_3 = (CH_2)_5$, R_2,R_4 = H	30	undetermined	91	3aα,8aα:3aα,8aβ (5.0:1.0)
cyclooctene	$R_1,R_3 = (CH_2)_6$, R_2,R_4 = H	50[b]	3α,3aα,9aα:3α,3aα,9aβ:3α,3aβ,9aα:3α,3aβ,9aβ (1.9:1.7:1.0:1.7)	89	3aα,9aα:3aα,9aβ (1.3:1.0)

[a] Isolated yield based on reacted alkene, typically 40%. [b] Spontaneous HCl elimination resulted in 10% yield of the α-methylene γ-lactone at this stage in addition to the α-chloromethyl γ-lactone.

Table III. Cyanoacetic Acid Lactonization and Conversion to α-Methylene γ-Lactones

alkene	α-cyano γ-lactone, 1, X = CN	yield, %[a]	stereochemistry (ratio)	α-methylene γ-lactone, %[b]	stereochemistry (ratio)
1-octene	$R_1 = C_6H_{13}$, R_2,R_3,R_4 = H	61	3α,5α:3α,5β (3.7:1.0)		
1-decene	$R_1 = C_8H_{17}$, R_2,R_3,R_4 = H	69	3α,5α:3α,5β (3.3:1.0)	73	
α-methylstyrene	R_1 = Ph, R_2 = Me, R_3,R_4 = H	70	3α,5α:3α,5β (1.5:1.0)	76	
cyclohexene	$R_1,R_3 = (CH_2)_4$, R_2,R_4 = H	46	3α,3aα,7aα:3α,3aα,7aβ:3α,3aβ,7aα :3α,3aβ,7aβ (6.8:1.0:1.0:1.9)	73	4α,5α:4α,5β (4.4:1.0)
cyclooctene	$R_1,R_3 = (CH_2)_6$, R_2,R_4 = H	66	3α,3aα,9aα:3α,3aα,9aβ:3α,3aβ,9aα :3α,3aβ,9aβ (1.6:1.0:9.6:2.1)	75	4α,5α:4α,5β (1.0:2.9)
2,3-dimethyl-2-butene	R_1,R_2,R_3,R_4 = Me	62			
ethylene	R_1,R_2,R_3,R_4 = H	4			
n-butyl crotonate	$R_1 = CO_2Bu$, R_2,R_4 = H, R_3 = Me	9	3α,4α,5β:3α,4β,5α (1.6:1.0)		

[a] Isolated yield. [b] The α-cyano lactones were reductively methylated (H_2, Ra Ni, CH_2O) and then treated sequentially with methyl iodide and sodium bicarbonate to yield the α-methylene γ-lactones.

It was apparent from our earlier study that carboxylic acids bearing electron-withdrawing groups would react at rates faster than acetic acid, and that this rate was directly related to the α-hydrogen acidity. Thus XCH_2CO_2H were more reactive than CH_3CO_2H by approximately the following factors: X = Cl (1×10^1), $PhSO_2$ (6×10^3), MeO_2S (1×10^4), and CN (3×10^5).[2] With this relative rate data in hand, a number of activated carboxylic acids were investigated for their synthetic potential, including $HOOCCH_2X$, X = Cl, CH_2Cl, CN, CO_2Me, S(O)Ph, SO_2Ph, NO_2, $P(O)(OEt)_2$, NMe_3^+, and Br. Of these, the latter six gave a plethora of products. However the first four gave synthetically useful and clean reactions. The results with the first three are summarized in Tables I–III.

The small oxidation rate enhancement (i.e., selectivity) of chloroacetic acid over acetic acid[10] required that lactone annulations with this acid be conducted in neat chloroacetic acid (Table I). Under these optimized conditions only a trace amount of the parent γ-lactone was produced by oxidation of an original acetate ligand within the starting manganese(III) oxidant. Although the use of a base in manganese(III) lactone annulations is generally beneficial, in this case, as well as that of 3-chloropropanoic acid, it led to formation of the 1,2-dichloro alkane as the predominant product.[11] The α-chloro lactones produced in this annulation process proved to be suitable precursors to α,β-unsaturated lactones. Direct elimination of HCl was not possible under a variety of conditions,[12,13] presumably because of the remaining acidic α-hydrogen. The rate of E2 elimination, however, is known to increase with iodide as a leaving group,[14] and so the labile α-iodo lactones were prepared by a Finkelstein reaction[15] and treated directly

(10) Typically α-chloro carbonyl compounds are more acidic than their parents by 2–3 pK_a units, see: Hine, J. "Structural Effects on Quilibria in Organic Chemistry"; Wiley-Interscience: New York, 1975; p 278. Reutov, O. A.; Beletskaya, I. P.; Butin, K. P. "CH-Acids"; Pergamon Press: Oxford, 1978; p 61.

(11) This result was subsequently turned into a successful chlorination procedure, see: Donnelly, K. D.; Fristad, W. E.; Gellerman, B. J.; Peterson, J. R.; Selle, B. J. *Tetrahedron Lett.* **1984**, *25*, 607–610.

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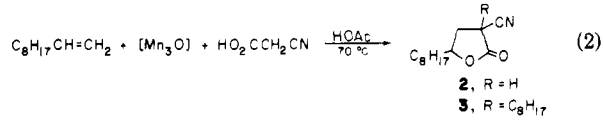
(14) Carey, F. A.; Sundberg, R. J. "Advanced Organic Chemistry"; Plenum Press: New York, 1977; Part A, pp 278–290.

with triethylamine (method A). For recalcitrant eliminations due to poor stereoelectronic overlap, Et_4NI was added to facilitate epimerization of the iodide (method B).[16] It should be noted that the thermodynamic stabilities of α,β- and β,γ-unsaturated γ-lactones can be very similar, and under these conditions an equilibrium is set up.[18] This three-step procedure represents one of the few methods of annulation of an α,β-unsaturated γ-lactone onto an olefin which does not simply involve dehydrogenating the saturated anlogue.[19] In addition, the regiochemistry of α-chloro lactone annulation is opposite to the commonly employed dichloroketene/Baeyer–Villiger oxidation sequence.[20]

Lactone annulation with 3-chloropropanoic acid was likewise performed in the neat acid because of the small rate enhancement over acetic acid oxidation (Table II). The α-chloromethyl γ-lactones thus produced were readily converted into the corresponding α-methylene γ-lactones by treatment with 1,8-bis(dimethylamino)naphthalene in refluxing THF. While the synthetic utility of this annulation/elimination is not as high as that of cyanoacetic acid (vida infra), it does demonstrate that no β-chlorine elimination took place. Elimination from radicals which bear β-leaving groups has been well documented,[21,22] and in particular β-chlorine elimination has been observed in radical addition to allylic chlorides.[23]

Cyanoacetic acid proved to be highly useful in the lactone annulation process (Table III). The reaction was complete within 10 min at 70 °C, compared to 2–3 h at 100–120 °C with the above chlorinated acids. An 8-fold excess of cyanoacetic acid was, however, still required to minimize further oxidation of the α-cyano lactone **2** to an α-cyano radical which added to 1-octene to produce **3** as shown in eq 2. The yields obtained for cyanolactonization were generally comparable to that of annulation with acetic acid, with the exception of *n*-butyl crotonate. The very electron deficient cyanoacetate radical added poorly (9% yield) to the already electron deficient unsaturated ester, whereas the complexed acetate radical added in 57% yield.[2]

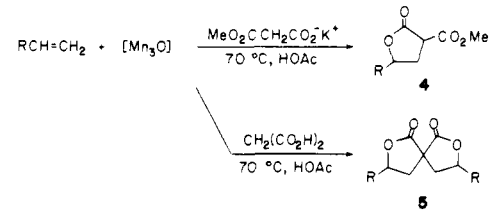


(2)

2, R = H
3, R = C_8H_{17}

The α-cyano lactones were subject to further synthetic manipulations as well. A facile reductive methylation ($RaNi/CH_2O/H_2$) followed by a literature quaternarization/elimination[24] procedure produced the corresponding α-methylene lactones in good yield (Table III). The overall yields for conversion of olefin to α-methylene lactone in this sequence compare favorably with all other known methods for this conversion.[25] Removal of the activating nitrile functionality could conceivably be accomplished by hydrolysis/decarboxylation or via reductive decyanation. The first route was reduced to practice as α-cyano-γ-dodecalactone **2** was hydrolyzed and decarboxylated[26] to γ-dodecalactone (97% yield) by refluxing in H_2O/H_3PO_4/HOAc (1/7/18) for 16 h; however reductive decyanation with Na/1-(dimethylamino)naphthalene/THF[27] at 25 °C resulted only in deprotonation, and treatment with 1% Na(Hg) in 1% aqueous THF produced 4-hydroxydodecanitrile in 17% yield. Thus the nitrile activator can be hydrolytically removed or converted into other functionality.

The success with cyanoacetic acid prompted us to investigate monomethylmalonic acid as an activated acid for the Mn(III) mediated annulation process. It was felt that the half acid ester should produce the α-carbomethoxy lactone **4** which would be a suitable precursor to further manipulation. This would also contrast with malonic acid itself which could not be prevented from lactonizing twice to **5**[8] (eq 3). The following results were in fact satisfying:



(3)

1-octene gave the α-carbomethoxy γ-lactone in 76%, cyclooctene in 67%, and cyclohexene in 39% yield. The cyclohexene result should be compared to a 29% yield when acetic acid was oxidized. Most of the remaining material was unreacted alkene and allylic acetate. It should be noted that these α-carbomethoxy γ-lactones can be decarbomethoxylated by standard NaCl/wet DMF conditions or merely refluxing the annulation reaction mixture for 12 h.

In summary, carboxylic acids with electron-withdrawing substituents may be used efficaciously in the Mn(III) mediated γ-lactone annulation procedure. The ease and rapidity of this synthetic transformation, as well as the double functionality introduced, warrants further synthetic exploitation.

Experimental Section

Melting points were determined with an Electrothermal apparatus and were uncorrected. ^1H NMR spectra were obtained on a Varian HFT-80 (80 MHz) or a Nicolet 300 MHz instrument. Chemical shifts were reported in parts per million relative to internal tetramethylsilane in deuteriochloroform unless specified otherwise. Mass spectra were obtained with an AE 1 Kratos MS-30 (electron impact) or a Finnigan 4000 (chemical ionization) spectrometer. Infrared and UV–visible spectra were obtained on Beckman 4250 and 3600 spectrophotometers, respectively. Infrared spectra of oils were obtained as thin films and solids as KBr pellets unless specified otherwise. Gas chromatography was performed with a Varian 3700 Model equipped with FID's and a Hewlett-Packard 3390A integrator. The columns used were 5% Carbowax 20M on 100/120 mesh Chromosorb W, 0.3 cm × 6 m

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(16) The Reich method of converting α-iodo esters into α,β-unsaturated esters (MCPBA) was only partially successful for our iodo lactones (33%).[17] The use of other oxidant systems was less useful yet (H_2O_2/PhCN, *t*-BuOOH/$Mo(CO)_6$, perphthalic acid).

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(27) Pardo, S. N.; Ghosh, S.; Salomon, R. G. *Tetrahedron Lett.* **1981**, *22*, 1885–1888.

or 10% SF-96 on 80/100 mesh Chromosorb W, 0.3 cm × 6 m to determine alkenes and reaction products. Product isolation by chromatography referred to medium-pressure liquid chromatography (FMI pump, Merck Lobar silica gel column, refractive index detector, Altex model 156) with ethyl acetate/hexane elution. All final products were pure as determined by analytical GC as above or by high-pressure liquid chromatography (Waters Associates model M-45 pump and U6K injector, Porasil column, 0.46 × 25 cm, refractive index detector, Altex Model 156) with ethyl acetate/hexane elution.

All reactions were magnetically stirred under a nitrogen atmosphere unless so indicated. A standard workup consisted of a 4–5-fold aqueous dilution of the reaction, extraction 3–4 times with the indicated organic solvent, washing the combined extracts 2 times each with water and saturated sodium bicarbonate, drying ($MgSO_4$), and rotary evaporation. The initial α-substituted lactone products were characterized by spectral data, and their ultimate conversion to known unsaturated lactones. Footnotes which follow compound names identify the original source. Manganese(III) acetate hydrate is abbreviated [Mn_3O] and was synthesized by the literature method.[28]

General Procedure for Chloroacetic Acid Lactone Annulation. A 50-mL round-bottom flask equipped with a reflux condenser was charged with the olefin (10.0 mmol), [Mn_3O] hydrate (8.04 g, 10.0 mmol), and chloroacetic acid (5.20 g, 55.0 mmol). The flask was immersed into an oil bath, which had been heated to 120 °C, until the dark brown color had disappeared (2–2.5 h). After being allowed to cool, the reaction was subjected to a standard workup/diethyl ether and chromatographed.

Structural Data for the α-Chloro Lactones in Table I. ***trans*-Dihydro-3-chloro-5-octyl-2(3*H*)-furanone**: elutes first, 10% EtOAc/hexane; IR 2930, 2860, 1785, 1470, 1350, 1195, 990, 925, 675 cm^{-1}; ^1H NMR δ 4.72 (quint, 1 H, J = 6 Hz), 4.42 (dd, 1 H, J = 3, 6.4 Hz), 2.7–2.0 (m, 2 H), 1.9–1.0 (m, 14 H), 0.88 (br t, 3 H, J = 6 Hz).

***cis*-Dihydro-3-chloro-5-octyl-2(3*H*)-furanone**: elutes second, 10% EtOAc/hexane; IR 2920, 2860, 1785, 1470, 1350, 1180, 1000, 940, 735 cm^{-1}; ^1H NMR δ 4.7–4.25 (m, 1 H), 4.55 (dd, 1 H, J = 8.5, 10.2 Hz), 2.9 (ddd, 1 H, J = 4.5, 8, 13 Hz), 2.1 (ddd, 1 H, J = 9, 10.5, 13 Hz), 1.9–1.0 (m, 14 H), 0.89 (br t, 3 H, J = 6 Hz).

(3α,4α,5α)-Dihydro-3-chloro-4,5-dipropyl-2(3*H*)-furanone: elutes fourth, 15% EtOAc/hexane; IR 2960, 2930, 2870, 1780, 1470, 1240, 1185, 965 cm^{-1}; ^1H NMR δ 4.7–4.25 (m, 1 H), 4.37 (d, 1 H, J = 7 Hz), 2.9–1.15 (m, 9 H), 1.15–0.65 (m, 6 H).

(3α,4α,5β)-Dihydro-3-chloro-4,5-dipropyl-2(3*H*)-furanone: elutes second, 15% EtOAc/hexane; IR 2960, 2930, 2870, 1780, 1470, 1240, 1220, 1195, 965 cm^{-1}; ^1H NMR δ 4.65–4.0 (m, 1 H), 4.38 (d, 1 H, J = 5.8 Hz), 2.6–1.15 (m, 9 H), 1.15–0.65 (m, 6 H).

(3α,4β,5α)-Dihydro-3-chloro-4,5-dipropyl-2(3*H*)-furanone: elutes third, 15% EtOAc/hexane; IR 2960, 2930, 2875, 1785, 1470, 1180, 965 cm^{-1}; ^1H NMR δ 4.5–3.8 (m, 1 H), 4.20 (d, 1 H, J = 9.8 Hz), 2.65–1.15 (m, 9 H), 1.15–0.65 (m, 6 H).

(3α,4β,5β)-Dihydro-3-chloro-4,5-dipropyl-2(3*H*)-furanone: elutes first, 15% EtOAc/hexane; IR 2960, 2920, 2870, 1785, 1470, 1190, 1160, 1150, 970, 920 cm^{-1}; ^1H NMR δ 4.8–4.55 (m, 1 H), 4.17 (d, 1 H, J = 7.1 Hz), 2.8–1.15 (m, 9 H), 1.15–0.65 (m, 6 H).

(3α,3aα,8aα)-Octahydro-3-chloro-2*H*-cyclohepta[*b*]furan-2-one: elutes first, 10% EtOAc/hexane; IR 2930, 2860, 1780, 1460, 1350, 1200, 1170, 1150, 995, 925 cm^{-1}; ^1H NMR δ 4.75 (ddd, 1 H, J = 4, 8, 11 Hz), 4.14 (d, 1 H, J = 7.6 Hz), 2.95–2.4 (m, 1 H), 2.4–1.0 (m, 10 H).

(3α,3aα,8aβ)-Octahydro-3-chloro-2*H*-cyclohepta[*b*]furan-2-one: elutes third, 10% EtOAc/hexane; IR 2940, 2870, 1790, 1450, 1375, 1240, 1175, 995, 825 cm^{-1}; ^1H NMR δ 4.3–3.8 (m, 1 H), 4.17 (d, 1 H, J = 11.6 Hz), 2.6–1.1 (m, 11 H).

(3α,3aβ,8aα)-Octahydro-3-chloro-2*H*-cyclohepta[*b*]furan-2-one: elutes second, 10% EtOAc/hexane; IR 2940, 2860, 1780, 1450, 1240, 1190, 1000 cm^{-1}; ^1H NMR δ 4.6–4.2 (m, 1 H), 4.35 (d, 1 H, J = 5.8 Hz), 2.65–2.15 (m, 1 H), 2.15–1.15 (m, 10 H).

(3α,3aβ,8aβ)-Octahydro-3-chloro-2*H*-cyclohepta[*b*]furan-2-one: elutes fourth, 10% EtOAc/hexane; IR 2930, 2860, 1780, 1460, 1365, 1185, 1165, 1005, 960, 930 cm^{-1}; ^1H NMR δ 4.85–4.45 (m, 1 H), 4.63 (d, 1 H, J = 7.9 Hz), 3.1–2.6 (m, 1 H), 2.5–1.05 (m, 10 H).

(3α,3aα,9aα)-Octahydro-3-chlorocycloocta[*b*]furan-2(3*H*)-one: elutes first, 10% EtOAc/hexane; IR 2920, 2850, 1785, 1470, 1450, 1350, 1250, 1210, 1170, 1135, 1110, 1020, 975, 960, 920, 860, 835, 825, 710 cm^{-1}; ^1H NMR δ 4.95–4.6 (m, 1 H), 4.12 (d, 1 H, J = 9.3 Hz), 2.8–2.25 (m, 1 H), 2.25–0.9 (m, 12 H).

(3α,3aα,9aβ)-Octahydro-3-chlorocycloocta[*b*]furan-2(3*H*)-one: elutes third, 10% EtOAc/hexane; IR 2920, 2860, 1785, 1470, 1450, 1360, 1315, 1260, 1185, 1080, 1005, 980, 970, 915, 825, 710 cm^{-1}; ^1H NMR δ 4.5–4.0 (m, 1 H), 4.18 (d, 1 H, J = 11 Hz), 2.65–1.0 (m, 13 H).

(3α,3aβ,9aα)-Octahydro-3-chlorocycloocta[*b*]furan-2(3*H*)-one: elutes second, 10% EtOAc/hexane; IR 2920, 2860, 1780, 1470, 1455, 1370, 1320, 1250, 1205, 1060, 1030, 1015, 985 cm^{-1}; ^1H NMR δ 4.65–4.15 (m, 1 H), 4.37 (d, 1 H, J = 5.9 Hz), 2.65–2.25 (m, 1 H), 2.25–1.1 (m, 12 H).

(3α,3aβ,9aβ)-Octahydro-3-chlorocycloocta[*b*]furan-2(3*H*)-one: elutes fourth, 10% EtOAc/hexane; IR 2930, 2860, 1780, 1470, 1450, 1360, 1350, 1225, 1180, 1150, 1110, 1060, 1020, 985, 955 cm^{-1}; ^1H NMR δ 4.9–4.4 (m, 1 H), 4.52 (d, 1 H, J = 7.3 Hz), 2.9–2.45 (m, 1 H), 2.4–1.0 (m, 12 H).

(3α,4β,5α)-Dihydro-4-(carboxymethyl)-3-chloro-5-phenyl-2(3*H*)-furanone: IR 3070, 3040, 3010, 2960, 1800, 1740, 1635, 1600, 1495, 1440, 1370, 1315, 1240, 1200, 1165, 985, 910, 765, 730, 695 cm^{-1}; ^1H NMR δ 7.39 (br s, 5 H), 5.49 (d, 1 H, J = 9.2 Hz), 4.96 (d, 1 H, J = 10.5 Hz), 3.79 (s, 3 H), 3.63 (dd, 1 H, J = 9.2, 10.5 Hz).

General Procedure for Iodo Lactone Preparation. The chloro lactone (1.08 mmol), sodium iodide (196 mg, 1.31 mmol), and acetone (2.2 mL) were refluxed for 6 h in a 10-mL round-bottom flask equipped with a reflux condenser. The flask was shielded from light throughout the reaction. After being allowed to cool, the reaction was diluted with diethyl ether (25 mL) and filtered. The filtrate was evaported to give crude iodo lactone as an orange oil.

General HI Elimination Procedure in Tetrahydrofuran (Method A). Crude iodo lactone (ca 1 mmol), triethylamine (131 mg, 1.30 mmol), and tetrahydrofuran (0.54 mL) were refluxed for 24 h in a 5-mL screw-capped test tube protected from light. The reaction was diluted with diethyl ether (15 mL) and washed with 2.5% hydrochloric acid (10 mL). The wash was extracted with diethyl ether (10 mL). The combined extracts were dried ($MgSO_4$), evaporated, and chromatographed (EtOAc:hexane, 1:7) to yield the α,β-unsaturated γ-lactone.

General HI Elimination Procedure in Triethylamine (Method B). Iodo lactone (ca 1 mmol), triethylamine (1.42 mL, 10.2 mmol), and tetraethylammonium iodide (131 mg, 0.51 mmol) were refluxed for 24 h in a 5-mL screw-capped test tube protected from light. The reaction was subjected to the above HI/THF elimination procedure workup and chromatographed to give the α,β-unsaturated β-unsaturated γ-lactone.

Structural Data for the α,β-Unsaturated γ-Lactones in Table I. 5-Octyl-2(5*H*)-furanone:[29] elutes second, 12% EtOAc/hexane; IR 3080, 2920, 2850, 1750, 1600, 1470, 1160, 1095, 1010, 910, 815 cm^{-1}; ^1H NMR δ 7.45 (dd, 1 H, J = 1.4, 5.7 Hz), 6.10 (dd, 1 H, J = 1.9, 5.7 Hz), 5.10–4.85 (m, 1 H), 1.85–1.05 (m, 14 H), 0.95 (br t, 3 H, J = 6 Hz); exact mass calcd for $C_{12}H_{20}O_2$ (m + 1)/z 197.1536, found 197.1504; calcd m/z 196.1458, found 196.1452.

5-Octyl-2(3*H*)-furanone:[30] elutes first, 12% EtOAc/hexane; IR 2950, 2920, 2850, 1800, 1675, 1470, 1395, 1375, 1260, 1180, 1150, 1105, 980, 930, 845, 735 cm^{-1}; ^1H NMR δ 5.08 (septet, 1 H, J = 1 Hz), 3.13 (dd, 2 H, J = 2, 3 Hz), 2.45–2.1 (m, 2 H), 1.85–1.1 (m, 12 H), 0.9 (br t, 3 H, J = 6 Hz).

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4,5-Dipropyl-2(5*H*)-furanone:[31] IR 3090, 2960, 2930, 2870, 1750, 1625, 1470, 1165, 1100, 910 cm^{-1}; ^{1}H NMR δ 5.77 (br d, 1 H, J = 1.6 Hz), 4.95–4.7 (m, 1 H), 2.45–2.1 (m, 2 H), 2.1–1.15 (m, 6 H), 1.15–0.6 (m, 6 H).

4,5,6,7,8,8a-Hexahydro-2*H*-cyclohepta[*b*]furan-2-one:[32] IR 3095, 2920, 2850, 1750, 1625, 1450, 1350, 1295, 1170, 1010, 910, 860, 720 cm^{-1}; ^{1}H NMR δ 5.76 (br d, 1 H, J = 1.4 Hz), 5.8–5.1 (m, 1 H), 3.0–2.55 (m, 2 H), 2.5–1.2 (m, 8 H, with peak at 1.80).

4,6,7,8,9,9a-Hexahydrocycloocta[*b*]furan-2(5*H*)-one:[32] IR 2925, 2855, 1745, 1630, 1440, 1350, 1295, 1160, 1005, 910, 865 cm^{-1}; ^{1}H NMR δ 5.75 (br d, 1 H, J = 1.5 Hz), 5.1–4.8 (m, 1 H), 3.0–1.3 (m, 12 H); exact mass calcd for $C_{10}H_{14}O_2$ (m + 1)/z 167.1068, found 167.1046; calcd m/z 166.0990, found 166.1000.

General Procedure for 3-Chloropropanoic Acid Lactone Annulation. A 50-mL round-bottom flask equipped with a reflux condenser was charged with the olefin (10.0 mmol), [Mn_3O] hydrate (8.04 g, 10.0 mmol), and 3-chloropropanoic acid (16.28 g, 150.0 mmol). The mixture was heated to 100 °C until the dark brown color disappeared (2–3 h), allowed to cool, subjected to a standard workup/diethyl ether, and chromatographed.

Structural Data for α-Chloromethyl Lactones in Table II. *cis*-Dihydro-3-(chloromethyl)-5-octyl-2(3*H*)-furanone: elutes second, 20% EtOAc/hexane; IR 2960, 2930, 2850, 1770, 1470, 1365, 1295, 1260, 1210, 1160, 1000 cm^{-1}; ^{1}H NMR δ 4.75–4.25 (m, 1 H), 3.80 (d, 2 H, J = 5 Hz), 3.2–2.85 (m, 1 H), 2.65–1.9 (m, 2 H), 1.85–1.1 (m, 14 H), 0.95 (br t, 3 H, J = 6 Hz).

***trans*-Dihydro-3-(chloromethyl)-5-octyl-2(3*H*)-furanone:** elutes first, 20% EtOAc/hexane; IR 2930, 2860, 1775, 1470, 1360, 1290, 1255, 1075, 1000 cm^{-1}; ^{1}H NMR δ 4.55–4.15 (m, 1 H), 3.76 (d, 2 H, J = 5 Hz), 3.25–2.85 (m, 1 H), 2.7–2.3 (m, 1 H), 2.15–1.85 (m, 1 H), 1.85–1.1 (m, 14 H), 0.95 (br t, 3 H, J = 6 Hz).

Dihydro-3-(chloromethyl)-4,5-dipropyl-2(3*H*)-furanone, diastereomeric mixture: IR 2960, 2930, 2870, 1770, 1455, 1370, 1185, 995 cm^{-1}; tentative ^{1}H NMR assignments of the 3α,4α,5α-isomer δ 4.7–4.5 (m, 1 H), 3.98 (dd, 1 H, J = 4, 11 Hz), 3.70 (dd, 1 H, J = 3, 11 Hz), 2.95–2.6 (m, 2 H), 2.0–0.7 (m, 14 H); the 3α,4α,5β-isomer 4.25 (m, 1 H), 4.0 (dd, 1 H, J = 4, 11 Hz), 3.7 (dd, 1 H, J = 3, 11 Hz), 2.72 (dt, 1 H, J = 9, 4 Hz), 2.55–1.95 (m, 1 H), 1.95–0.7 (m, 14 H); the 3α,4β,5α- or 3α,4β,5β-isomer 4.40–4.15 (m, 1 H), 3.87 (dd, 1 H, J = 4, 11 Hz), 3.62 (dd, 1 H, J = 8, 11 Hz), 3.12 (dt, 1 H, J = 4, 8 Hz), 2.45–2.1 (m, 1 H), 1.9–0.7 (m, 14 H).

Octahydro-3-(chloromethyl)-2*H*-cyclohepta[*b*]furan-2-one, diastereomeric mixture: IR 2930, 2860, 1775, 1445, 1175, 995 cm^{-1}; ^{1}H NMR δ 4.8–4.35 (m, 1 H), 3.88 (br dd, 1 H, J = 4, 11 Hz), 3.65 (br dd, 1 H, J = 3, 11 Hz), 2.95–2.45 (m, 2 H), 2.25–1.0 (m, 10 H).

(3α,3aα,9aα)-Octahydro-3-(chloromethyl)cycloocta[*b*]furan-2(3*H*)-one: elutes fourth, 15% EtOAc/hexane; ^{1}H NMR δ 4.55–4.15 (m, 1 H), 3.70 (br t, 2 H, J = 7 Hz), 2.95–2.35 (m, 2 H), 2.3–1.0 (m, 12 H).

(3α,3aα,9aβ)-Octahydro-3-(chloromethyl)cycloocta[*b*]furan-2(3*H*)-one: elutes third, 15% EtOAc/hexane; ^{1}H NMR δ 4.7–4.35 (m, 1 H), 3.9 (dd, 1 H, J = 4, 11 Hz), 3.65 (dd, 1 H, J = 3, 11 Hz), 3.02 (ddd, 1 H, J = 3, 4, 10 Hz), 2.85–2.35 (m, 1 H), 2.35–1.0 (m, 12 H).

(3α,3aβ,9aα)-Octahydro-3-(chloromethyl)cycloocta[*b*]furan-2(3*H*)-one: elutes second, 15% EtOAc/hexane; ^{1}H NMR δ 4.6–4.2 (m, 1 H), 3.92 (dd, 1 H, J = 4, 11 Hz), 3.65 (dd, 1 H, J = 3, 11 Hz), 3.0–2.35 (m, 2 H), 2.3–1.0 (m, 12 H).

(3α,3aβ,9aβ)-Octahydro-3-(chloromethyl)cycloocta[*b*]furan-2(3*H*)-one: elutes first, 15% EtOAc/hexane; IR (mixture of all isomers) 2930, 2850, 1775, 1475, 1450, 1185, 985 cm^{-1}; ^{1}H NMR δ 4.9–4.55 (m, 1 H), 4.0 (dd, 1 H, J = 4, 12 Hz), 3.7 (dd, 1 H, J = 4, 12 Hz), 3.0–2.45 (m, 2 H), 2.3–1.0 (m, 12 H).

General HCl Elimination Procedure for α-Chloromethyl γ-Lactones. The α-chloromethyl γ-lactone (0.20 mmol), Proton Sponge[33] (65 mg, 0.30 mmol), and tetrahydrofurn (0.25 mL) were refluxed for 9–12 h in a 5-mL screw-capped test tube. The reaction was diluted with diethyl ether (15 mL) and washed with water (10 mL), saturated cupric sulfate solution (2 × 10 mL), and 2.5% hydrochloric acid (10 mL). After drying ($MgSO_4$) and evaporation, the product was chromatographed.

Structural Data for the α-Methylene γ-Lactones in Table II. Dihydro-3-methylene-5-octyl-2(3*H*)-furanone:[34] IR 2920, 2845, 1765, 1665, 1460, 1270, 1250, 1110, 1000, 930, 810 cm^{-1}; ^{1}H NMR δ 6.20 (d, 1 H, J = 3 Hz), 5.61 (d, 1 H, J = 2.5 Hz), 4.50 (quint, 1 H, J = 6 Hz), 3.05 (ddt, 1 H, J = 17, 7.5, 2.5 Hz), 2.53 (ddt, 1 H, J = 17, 6, 3 Hz), 1.95–1.1 (m, 14 H), 0.95 (br t, 3 H, J = 6 Hz); exact mass calcd for $C_{13}H_{22}O_2$ m/z 210.1614, found 210.1627.

***cis*-Dihydro-3-methylene-4,5-dipropyl-2(3*H*)-furanone:**[34] elutes second, 10% EtOAc/hexane; IR 2960, 2930, 2870, 1765, 1670, 1470, 1405, 1265, 1165, 1130, 1110, 975, 950, 815 cm^{-1}; ^{1}H NMR δ 6.19 (d, 1 H, J = 2.4 Hz), 5.49 (d, 1 H, J = 2.2 Hz), 4.65–4.25 (m, 1 H), 3.1–2.7 (m, 1 H), 1.8–1.15 (m, 8 H), 0.96 (br t, 6 H, J = 6 Hz).

***trans*-Dihydro-3-methylene-4,5-dipropyl-2(3*H*)-furanone:**[34] elutes first, 10% EtOAc/hexane; IR 2960, 2930, 2880, 1765, 1665, 1470, 1405, 1270, 1120, 990, 815 cm^{-1}; ^{1}H NMR δ 6.24 (d, 1 H, J = 2.6 Hz), 5.56 (d, 1 H, J = 2.3 Hz), 4.17 (br q, 1 H, J = 6 Hz), 2.8–2.45 (m, 1 H), 1.75–1.15 (m, 8 H), 1.5–0.65 (m, 6 H).

***cis*-Octahydro-3-methylene-2*H*-cyclohepta[*b*]furan-2-one:**[35] elutes second, 10% EtOAc/hexane; IR 2930, 2860, 1760, 1660, 1445, 1400, 1335, 1275, 1160, 1125, 995, 940, 815 cm^{-1}; ^{1}H NMR δ 6.27 (d, 1 H, J = 3.0 Hz), 5.53 (d, 1 H, J = 2.7 Hz), 4.67 (br dt, 1 H, J = 3, 9 Hz), 3.4–2.95 (m, 1 H), 2.25–0.9 (m, 10 H).

***trans*-Octahydro-3-methylene-2*H*-cyclohepta[*b*]furan-2-one:**[32] elutes first, 10% EtOAc/hexane; IR 2930, 2860, 1765, 1665, 1450, 1400, 1310, 1260, 1245, 1150, 1125, 995, 940, 810 cm^{-1}; ^{1}H NMR δ 6.17 (d, 1 H, J = 3 Hz), 5.44 (d, 1 H, J = 3 Hz), 4.35–3.95 (m, 1 H), 3.0–2.5 (m, 1 H), 2.5–1.15 (m, 10 H, with peak at 1.65).

General Synthetic Procedure for Cyanoacetic Acid Lactone Annulation. The alkene (5.00 mmol), [Mn_3O] hydrate (2.74 g, 3.41 mmol), cyanoacetic acid (3.40 g, 40.0 mmol), and glacial acetic acid (50 mL) were heated at 70 °C in a 100-mL round-bottom flask equipped with a reflux condenser until the dark brown color disappeared (10–15 min). The mixture was allowed to cool, subjected to a standard workup/diethyl ether, and chromatographed.

Structural Data for the α-Cyano Lactones in Table III. *cis*-Dihydro-3-cyano-5-hexyl-2(3*H*)-furanone: elutes second, 30% EtOAc/hexane; IR 2930, 2850, 2250, 1785, 1460, 1170, 1010, 980, 910 cm^{-1}; ^{1}H NMR δ 4.85–4.25 (m, 1 H), 3.82 (dd, 1 H, J = 8, 12 Hz), 2.95–1.9 (m, 2 H), 1.9–0.55 (m, 13 H).

***trans*-Dihydro-3-cyano-5-hexyl-2(3*H*)-furanone:** elutes first, 30% EtOAc/hexane; IR 2930, 2850, 2250, 1780, 1465, 1170, 1020, 970, 905 cm^{-1}; ^{1}H NMR δ 4.75–4.3 (m, 1 H), 3.7 (dd, 1 H, J = 9, 12 Hz), 2.95–2.0 (m, 2 H), 1.9–0.6 (m, 13 H).

Dihydro-3-cyano-5-octyl-2(3*H*)-furanone, 3.3:1.0 cis–trans mixture: IR 2920, 2850, 2250, 1780, 1460, 1175, 1010, 975, 910, 730 cm^{-1}; ^{1}H NMR δ 4.85–4.2 (m, 1 H), 3.7 (dd, 0.77 H, J = 9, 11 Hz), 3.65 (dd, 0.23 H, J = 9, 11 Hz), 1.9–0.7 (m, 17 H); exact mass calcd for $C_{13}H_{21}NO_2$ m/z 223.1566, found 223.1583.

3α,5α- and 3α,5β-Dihydro-3-cyano-5-methyl-5-phenyl-2-(3*H*)-furanone, 1.5:1.0 diastereomeric mixture: IR 3060, 3030, 2980, 2910, 2250, 1785, 1600, 1495, 1445, 1380, 1300, 1245, 1220, 1140, 985, 950, 765, 705 cm^{-1}; ^{1}H NMR δ 7.34 (br s, 5 H), 4.02 (dd, 0.4 H, J = 9, 11 Hz), 3.48 (dd, 0.6 H, J = 8, 12 Hz), 3.15–2.45 (m, 2 H), 1.77 (s, 1.8 H), 1.68 (s, 1.2 H); exact mass calcd for $C_{12}H_{11}NO_2$ (m + 1)/z 202.0864, found 202.0835; calcd m/z 201.0786, found 201.0784.

(3α,3aα,7aα)- and (3α,3aβ,7aβ)-Hexahydro-3-cyano-2-(3*H*)-benzofuranone, 1.0:3.6 diastereomeric mixture: elutes second, 30% EtOAc/hexane; IR 2940, 2860, 2250, 1780, 1445, 1355, 1330, 1245, 1210, 1170, 1150, 1135, 1075, 1025, 990, 965, 730 cm^{-1}; ^{1}H NMR δ 4.85–4.45 (m, 1 H), 3.97 (d, 0.78 H, J = 6.1 Hz), 3.55 (d, 0.22 H, J = 8.0 Hz), 3.05–2.5 (m, 1 H), 2.5–1.0 (m, 8 H); exact mass calcd for $C_9H_{11}NO_2$ (m + 1)/z = 166.0865, found 166.0846.

(3α,3aα,7aβ)- and (3α,3aβ,7aα)-Hexahydro-3-cyano-2-(3*H*)-benzofuranone, 1.0:1.0 diastereomeric mixture: elutes first, 30% EtOAc/hexane; IR 2940, 2860, 1780, 1450, 1355, 1255,

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1245, 1215, 1185, 1145, 1010, 970, 915, 735 cm^{-1}; ^{1}H NMR δ 4.75–4.45 (m, 1 H), 3.85 (d, 0.5 H, J = 6.0 Hz), 3.42 (d, 0.5 H, J = 12.7 Hz), 3.0–2.5 (m, 1 H), 2.5–1.0 (m, 8 H).

(3α,3aα,9aβ)-, (3α,3aβ,9aα)-, (3α,3aβ,9aβ)-, and (3α,3aα,9aα)-Octahydro-3-cyanocycloocta[*b*]furan-2(3*H*)-one, 9.6:1.0:1.6:2.1 diastereomeric mixture: IR 2930, 2860, 2260, 1785, 1475, 1450, 1195, 1175, 985, 725 cm^{-1}; ^{1}H NMR δ 4.65–4.25 (m, 1 H), 4.07 (d, 0.11 H, J = 7 Hz), 3.87 (d, 0.07 H, J = 4 Hz), 3.56 (d, 0.67 H, J = 12 Hz), 3.47 (d, 0.15 H, J = 12 Hz), 2.9–2.45 (m, 1 H), 2.4–0.9 (m, 12 H).

Dihydro-3-cyano-4,4,5,5-tetramethyl-2(3*H*)-furanone: IR 2980, 2905, 2250, 1775, 1475, 1460, 1405, 1390, 1380, 1325, 1275, 1230, 1190, 1160, 1125, 1090, 1030, 980, 955, 935, 860 cm^{-1}; ^{1}H NMR δ 3.95 (s, 1 H), 1.40 (s, 6 H), 1.24 (s, 6 H).

Dihydro-3-cyano-2(3*H*)-furanone: IR 2920, 2260, 1775, 1485, 1455, 1375, 1255, 1220, 1155, 1020, 980, 950, 920, 805, 730, 705 cm^{-1}; ^{1}H NMR δ 4.7–4.1 (m, 2 H), 3.76 (dd, 1 H, J = 9.0, 10.6 Hz), 3.0–2.3 (m, 2 H).

(3α,4α,5β)- and (3α,4β,5α)-Dihydro-5-(carboxybutyl)-3-cyano-4-methyl-2(3*H*)-furanone, 1.6:1.0 diastereomeric mixture: IR 2970, 2940, 2880, 2260, 1805, 1750, 1465, 1395, 1360, 1300, 1285, 1200, 1155, 1060, 1030, 730 cm^{-1}; ^{1}H NMR δ 4.63 (d, 0.38 H, J = 7.5 Hz), 4.56 (d, 0.62 H, J = 14 Hz), 4.26 (t, 1.24 H, J = 6.4 Hz), 4.23 (t, 0.76 H, J = 6.4 Hz), 4.03 (d, 0.38 H, J = 7.9 Hz), 3.48 (d, 0.62 H, J = 10.8 Hz), 3.3–2.75 (m, 1 H), 1.53 (s, 1.86 H), 1.44 (s, 1.14 H), 2.0–0.7 (m, 9 H).

General Procedure for Catalytic Hydrogenation of α-Cyano Lactones; Preparation of Dihydro-3-[(*N*,*N*-dimethylamino)methyl]-5-octyl-2(3*H*)-furanone. A 250-mL Paar hydrogenation bottle was charged with the corresponding α-cyano lactone (500 mg, 2.24 mmol), 37% aqueous formaldehyde (5.47 g, 67.2 mmol), W-2 Ra-Ni (300 mg), and ethanol (13 mL). The vessel was shaken at 25 °C for 72 h under 50 psi H_2 before filtering and washing the catalyst with ethanol (5 mL). After evaporation, the residue was diluted with water (20 mL), ammonium hydroxide (1 mL) added, and extracted with chloroform (3 × 20 mL). The combined extracts were dried (Na_2CO_3) and evaporated to give the title dimethylamino lactone (569 mg, 100%) as crude diasteromeric mixture: IR 3460, 2930, 2860, 2830, 2780, 1770, 1465, 1200, 1040 cm^{-1}; ^{1}H NMR δ 4.9–4.25 (m, 1 H), 3.95–3.45 (m, 2 H), 2.8–1.9 (m, 3 H), 2.32 (s, 6 H), 1.9–0.7 (m, 17 H).

General Procedure for Preparation of α-Methylene γ-Lactones.[24] Dihydro-3-methylene-5-octyl-2(3*H*)-furanone.[35] The above dimethylamino lactone (182 mg, 0.71 mmol) and methyl iodide (3.03 g, 21.4 mmol) were stirred for 16 h at 25 °C in a 5-mL screw-capped test tube protected from the light. The mixture was poured onto methylene chloride (10 mL) and saturated sodium bicarbonate (20 mL). After vigorous shaking, the phases were separated and the aqueous phase extracted with methylene chloride (3 × 6 mL). The combined extracts were dried (Na_2CO_3) and evaporated to an oil (162 mg). Flash distillation (100 °C (0.2 mmHg)) afforded the α-methylene lactone (110 mg, 0.52 mmol, 73%).

Structural Data for the α-[(*N*,*N*-Dimethylamino)methyl] Lactones and New α-Methylene γ-Lactones in Table III. Dihydro-3-[(*N*,*N*-dimethylamino)methyl]-5-methyl-5-phenyl-2(3*H*)-furanone, crude diastereomeric mixture: IR 3460, 3090, 2060, 3030, 2980, 2950, 2870, 2830, 2780, 1760, 1605, 1495, 1445, 1375, 1290, 1235, 1150, 1060, 955, 760, 700 cm^{-1}; ^{1}H NMR δ 7.30 (br s, 5 H), 4.6–4.2 (m, 2 H), 3.9–2.4 (m, 3 H), 2.32 (s, 1.5 H), 2.09 (s, 1.5 H), 1.75 (s, 3 H).

Dihydro-5-methyl-3-methylene-5-phenyl-2(3*H*)-furanone:[36] IR 3095, 3060, 3030, 2980, 2930, 2860, 1760, 1665, 1600, 1495, 1445, 1400, 1380, 1275, 1205, 1115, 1085, 1055, 1030, 950, 810, 765, 700 cm^{-1}; ^{1}H NMR δ 7.35 (br s, 5 H), 6.25 (t, 1 H, J = 2.7 Hz), 5.63 (t, 1 H, J = 2.5 Hz), 3.15 (t, 2 H, J = 2.6 Hz), 1.72 (s, 3 H); exact mass calcd for $C_{12}H_{12}O_2$ (m + 1)/z 189.0912, found 189.0867; calcd m/z 188.0834, found 188.0839.

Hexahydro-3-[(*N*,*N*-dimethylamino)methyl]-2(3*H*)-benzofuranone, crude diastereomeric mixture:[37,38] IR 3380, 2930, 2860, 2830, 2780, 1770, 1460, 1195, 1180, 1130, 1060, 1025, 980, 960 cm^{-1}; ^{1}H NMR δ 4.75–4.60 (m, 0.2 H), 3.78 (br s, 0.8 H), 4.05–3.35 (m, 2 H), 2.36 (s, 6 H), 3.1–0.7 (m, 10 H).

Hexahydro-3-methylene-2(3*H*)-benzofuranone, 4.3:1 cis–trans mixture:[38,39] IR 2930, 2860, 1765, 1665, 1450, 1310, 1295, 1260, 1230, 1160, 1125, 1100, 1010, 980, 965, 815 cm^{-1}; ^{1}H NMR δ 6.18 (d, 0.81 H, J = 2.5 Hz), 6.05 (d, 0.19 H, J = 3.2 Hz), 5.52 (d, 0.81 H, J = 2.3 Hz), 5.38 (d, 0.19 H, J = 2.9 Hz), 4.95–4.4 (m, 1 H), 3.3–2.8 (m, 1 H), 2.8–0.85 (m, 8 H); exact mass calcd for $C_9H_{12}O_2$ (m + 1)/z = 153.0912, found 153.0889; calcd m/z 152.0834, found 152.0831.

Octahydro-3-[(*N*,*N*-dimethylamino)methyl]cycloocta[*b*]furan-2(3*H*)-one, crude diastereomeric mixture: IR 3460, 2930, 2860, 2830, 2780, 1765, 1460, 1330, 1260, 1230, 1180, 1150, 1075, 1040, 1025, 995, 970, 840 cm^{-1}; ^{1}H NMR δ 4.9–4.4 (m, 1 H), 3.9–3.15 (m, 2 H), 3.15–0.9 (m, 14 H), 2.23 (s, 6 H).

Octahydro-3-methylenecycloocta[*b*]furan-2(3*H*)-one, 1.0:2.9 cis–trans mixture:[40,41] IR 2920, 2860, 1760, 1660, 1470, 1450, 1400, 1310, 1270, 1150, 1030, 990, 960, 950, 810 cm^{-1}; ^{1}H NMR δ 6.24 (d, 0.26 H, J = 3.0 Hz), 6.22 (d, 0.74 H, J = 3.2 Hz), 5.54 (d, 0.26 H, J = 3 Hz), 5.51 (d, 0.74 H, J = 2.9 Hz), 4.6–4.2 (m, 1 H), 3.15–2.6 (m, 1 H), 2.6–0.85 (m, 12 H); exact mass calcd for $C_{11}H_{16}O_2$ (m + 1)/z 181.1224, found 181.1185; calcd m/z 180.1146, found 180.1149.

General Procedure for α-Carboxymethyl γ-Lactone Annulation. A 50-mL round-bottom flask equipped with a reflux condenser was charged with [Mn_3O] hydrate (4.2 mmol), alkene (2.0 mmol), potassium methyl malonate (50.2 mmol), and acetic acid (20 mL). This mixture was placed in an oil bath at 70 °C. The reaction turned from dark brown to light yellow in 10–12 min. The solution was cooled and worked up. The ester lactones were purified by either chromatography or vacuum distillation.

The α-carboxymethyl γ-lactones were converted to the known parent γ-lactones by refluxing the reaction mixture for 1–2 days followed by the usual workup,[42] or by heating with NaCl in wet DMF.[43]

Dihydro-3-(carboxymethyl)-5-hexyl-2(3*H*)-furanone (1:1 cis–trans): IR 2960, 2930, 2860, 1780, 1740, 1440, 1355, 1260, 1160, 990 cm^{-1}; ^{1}H NMR δ 4.0–4.75 (m, 1 H), 3.81 (s, 1.5 H), 3.79 (s, 1.5 H), 3.65–3.45 (m, 1 H), 2.42 (m, 2 H), 2.0–0.4 (m, 13 H); Kugelrohr oven 150 °C (0.2 torr).

(3α,3aα,7aα)- and (3α,3aα,7aβ)-Hexahydro-3-(carboxymethyl)-2(3*H*)-benzofuranone (1.0:1.3):[44] IR 3000, 2935, 2860, 1775, 1735, 1445, 1435, 1345, 1295, 1250, 1165, 1120, 1100, 1035, 1015, 985, 940, 720 cm^{-1}; ^{1}H NMR δ 4.68 (q, 0.44 H, J = 6 Hz), 4.46 (q, 0.56 H, J = 6 Hz), 3.78 (s, 3 H), 3.33 (d, 0.44 H, J = 6 Hz), 2.78 (m, 1 H), 2.5–0.8 (m, 8 H).

(3α,3aα,9aα)- and (3α,3aα,9aβ)-Octahydro-3-(carboxymethyl)cycloocta[*b*]furan-2(3*H*)-one (5.7:1.0):[41] IR 2920, 2855, 1775, 1740, 1455, 1445, 1435, 1350, 1275, 1185, 1160, 1135, 1120, 1030, 995 cm^{-1}; ^{1}H NMR δ 4.29 (br dt, 1 H, J = 4, 9 Hz), 3.81 (s, 3 H), 3.28 (d, 1 H, J = 11 Hz), 2.95–2.5 (m, 1 H), 2.5–0.8 (m, 12 H); Kugelrohr oven 130 °C (0.2 torr).

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