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Proto- and Iodo-lactonization Reaction of Substituted $\alpha,\beta : \gamma,\delta$-Unsaturated Carboxylic Acid

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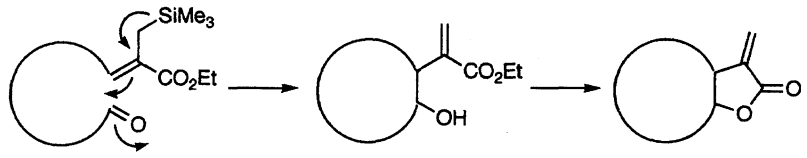
Iodolactonization of 4,5-disubstituted 2-(trimethylsilylmethyl)- and 2-methyl-penta-2,4-dienoic acids was studied. The latter afforded the corresponding iodolactone in good yield by treatment with I_2 in MeCN. Iodolactone was also obtained by treatment with $I_2/NaHCO_3/CHCl_3/H_2O$ in the presence of cerium(IV) salt as an additive. It was found that protolactonization proceeds by the aid of the trimethylsilyl group, while it prevents iodolactonization.

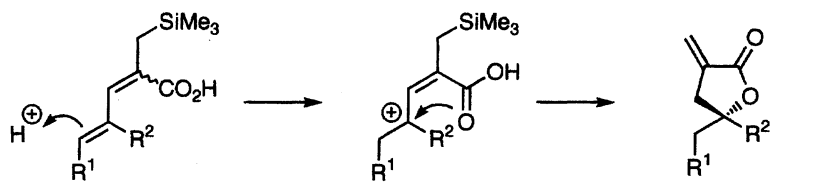
A number of biologically active natural terpenoids have the lactone structure.[1,2] We are investigating the synthesis of α-methylene-γ-lactones fused to various carbocycles utilizing the reaction of functionalized allylsilanes (intramolecular Hosomi reaction), as shown in general Scheme 1.[3] We recently reported that treatment of 4,5-disubstituted 2-(trimethylsilylmethyl)penta-2,4-dienoic acids **1a** and **1b** with trifluoromethanesulfonic acid (TfOH) in acetonitrile (Ritter condition) affords methylenelactones **2a** and **2b**, respectively.[4] Using conjugated allylsilanes at the β-position, the process of this reaction (protolactonization) is completely different from Scheme 1, and is considered to proceed as shown in Scheme 2. Thus protonation at the δ-position of $\alpha,\beta : \gamma,\delta$-unsaturated acid **1** first occurs to give silicon-stabilized tertiary carbocation **3**, to which oxygen atom attacks followed by protodesilylation to afford lactone **2**. This mechanism is similar to that of iodolactonization, if the proton is replaced by an iodo cation. Then our attention was next focused on the iodolactonization reaction, based on the assumption that the reaction would proceed by a similar mechanism to afford the corresponding iodolactone. Iodolactonization is an essential technique in organic synthesis, and is often used in the synthesis of natural products or its derivatives.[5] As basic studies on iodolactonization, stereoselective lactonizations[6] and macrocyclizations[7] have been developed recently.[8] Here we report that the iodolactonization of $\alpha,\beta : \gamma,\delta$-unsaturated acid proceeds by I_2/MeCN or $I_2/NaHCO_3/Ce(IV)/CHCl_3/H_2O$, and that the reaction is not the same as protolactonization.

Results and Discussion

As the substrate of this study, we first chose compound **1a**, which was prepared as in our previous report.[4] The iodolactonization reaction was done in three ways; $I_2/NaHCO_3/CHCl_3/H_2O$ (method A),[9] I_2/MeCN (method B),[9,10] and $I_2/NaHCO_3/KI/H_2O$/THF (method C).[11] However, the expected lactone **4** was obtained in only 11% yield by method B (Scheme 3), while method A and C produced no lactones. Under these conditions, many undefined by-products were detected on TLC. The product **4** was obtained as

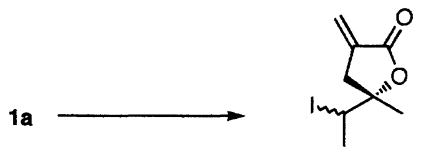


Scheme 1.



1a $R^1=R^2=Me$ **3a** $R^1=R^2=Me$ **2a** $R^1=R^2=Me$
1b $R^1,R^2=(CH_2)_4$ **3b** $R^1,R^2=(CH_2)_4$ **2b** $R^1,R^2=(CH_2)_4$

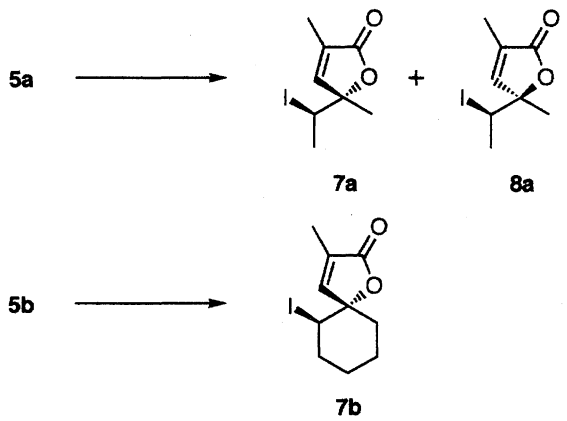
Scheme 2.



Scheme 3. Reagents and conditions: I_2, MeCN, r.t.

a single diastereomer, however its stereochemistry was not identified.

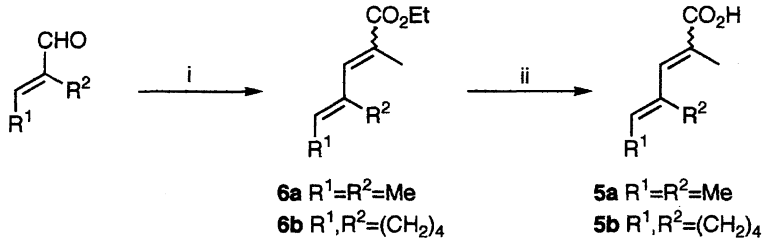
To discover the role of the silyl group in this proto- and iodo-lactonization reaction, the desilylated compound **5a** was then prepared according to Scheme 4. Thus the Wittig reaction of (*E*)-2-methylbut-2-enal with $(EtO)_2P(O)CHMeCO_2Et$ gave **6a** (44%), which was hydrolyzed to afford acid **5a** (89%). Compound **5a** was obtained as a mixture of two geometrical isomers (about 3 : 2 ratio). Although separation was not made, the major isomer had the (2*E*)-configuration from the NOESY spectrum. When **5a** was treated under iodolactonization conditions, the expected lactone was obtained in 30% yield by method A, and 74% by method B, while no reaction proceeded at all when method C was used. It was found that the product consists of two stereoisomers **7a** and **8a** (Scheme 5). The ratio of the two isomers was about 1.2 : 1 from the ^{1}H NMR spectrum. In contrast, when **5a** was exposed to the protolactonization conditions (TfOH in



Scheme 5. Reagents and conditions: see text.

MeCN), the substrate was recovered without reaction. This indicates that the silyl group is necessary for the protolactonization reaction, i.e., the C=C double bond of conjugated acid **1a** is activated by a silicon atom, and the reaction proceeds through silyl-stabilized carbocation,[12] as described in Scheme 2. In contrast, by using the more reactive iodo cation, iodolactonization proceeded without silyl activation.

Recently, Horiuchi et al. reported that Ce(IV) salts such as $Ce(NH_4)_2(NO_3)_6$ or $Ce(SO_4)_2{\cdot}4H_2O$ activate I_2 in the addition reaction.[13] Thus on the basis of method A, the effect of Ce(IV) salt as an additive was studied. The results



Scheme 4. Reagents and conditions: i, $(EtO)_2P(O)CHMeCO_2Et$, NaH, DME, r.t.; ii, KOH, MeOH, H_2O, 95 °C.

Table 1. Effect of Ce(VI) Salt in the Iodolactonization of **5a**,**b**[a)]

Entry	Substrate	Additive	Molar amount	Product[b)]	Yield/%
1	**5a**	None	—	**7a**, **8a**	30
2	**5a**	$Ce(SO_4)_2{\cdot}4H_2O$	0.01	**7a**, **8a**	29
3	**5a**	$Ce(SO_4)_2{\cdot}4H_2O$	0.1	**7a**, **8a**	45
4	**5a**	$Ce(SO_4)_2{\cdot}4H_2O$	0.5	**7a**, **8a**	65
5	**5a**	$Ce(SO_4)_2{\cdot}4H_2O$	1	**7a**, **8a**	68
6	**5a**	$Ce(SO_4)_2{\cdot}4H_2O$	2	**7a**, **8a**	35
7	**5a**	$Ce(SO_4)_2{\cdot}4H_2O$	3	**7a**, **8a**	20
8	**5a**	$Ce(NH_4)_2(NO_3)_6$	0.01	**7a**, **8a**	30
9	**5a**	$Ce(NH_4)_2(NO_3)_6$	0.1	**7a**, **8a**	34
10	**5a**	$Ce(NH_4)_2(NO_3)_6$	0.5	**7a**, **8a**	47
11	**5a**	$Ce(NH_4)_2(NO_3)_6$	1	**7a**, **8a**	49
12	**5a**	$Ce(NH_4)_2(NO_3)_6$	2	**7a**, **8a**	48
13	**5a**	$Ce(NH_4)_2(NO_3)_6$	3	**7a**, **8a**	25
14	**5b**	$Ce(SO_4)_2{\cdot}4H_2O$	1	**7b**	64
15	**5b**	$Ce(NH_4)_2(NO_3)_6$	1	**7b**	51

a) All reactions were carried out with I_2 (2 molar amounts) and $NaHCO_3$ (2 molar amounts) in $H_2O/CHCl_3$ as solvent at room temperature. b) Two isomers **7a** and **8a** were obtained in 1.1:1 to 1.4:1 ratio; **7b** was obtained as a single isomer.

are summarized in Table 1. Among tested amounts of $Ce(SO_4)_2 \cdot 4H_2O$ (Entries 2—7), a good result was obtained when 1 molar amount of the salt was added (Entry 5), however, more additive gave less satisfactory results (Entries 6, 7). The addition of $Ce(NH_4)_2(NO_3)_6$ showed mostly parallel results (Entries 8—13), i.e., addition of 1 molar amount of the salt produced the best yield. With 1 molar amount of $Ce(SO_4)_2 \cdot 4H_2O$, solvent effect of this reaction was also studied (Table 2). However, none of them used were better than $CHCl_3$, except CH_2Cl_2 (Entry 2). The addition of $Ce(SO_4)_2 \cdot 4H_2O$ to the solution of I_2 in MeCN without $NaHCO_3$, which corresponds to method B, was examined but the yield was decreased to 28% (Entry 9).

Spiro-iodolactonization reaction was also done using **5b** as the substrate, which was prepared from 1-cyclohexenecarbaldehyde (Scheme 4). Compound **5b** was obtained as only (2*E*)-isomer. On treatment of **5b** under the conditions of Method B (I_2 in MeCN), the lactone **7b** was obtained in 51% yield as a single diastereomer (Scheme 5), the stereochemistry of which was analyzed by NOESY spectrum as shown in Fig. 1. Treatment of **5b** by method A with 1 molar amount of $Ce(SO_4)_2 \cdot 4H_2O$ or $Ce(NH_4)_2(NO_3)_6$ as additives resulted in formation of **7b** in 64 or 51% yields, respectively (Table 1, Entries 14 and 15).

As for the stereochemistry of the iodolactonization reaction, it is obvious that the isomerization of α,β-double bond occurs before the cyclization, as reported earlier,[4] since (2*E*)-precursor **5b** produced **7b**, which must be obtained from the (2*Z*)-isomer. In addition to this, the presence of free rotation at the γ,δ-bond of the intermediate was suggested, since **5a** afforded two isomers **7a** and **8a**. Thus as shown in Scheme 6, the initial iodonium ion **i** from **5a** cyclize to oxonium ion **ii**, which affords **7a**. The intermediate **i** and **ii** are also in equilibrium with **iii**, an allylic cation. Free rotation of the C–C single bond of **iii** enables further equilibration between **iii**

Table 2. Solvent Effect of the Iodolactonization of **5a**[a)]

Entry	Solvent	Yield/%	Entry	Solvent	Yield/%
1	$CHCl_3$	68	6	THF	0
2	CH_2Cl_2	67	7	*t*-BuOH	0
3	MeOH	27	8	MeCN	39
4	Acetone	0	9	MeCN[b)]	28
5	Et_2O	7			

a) All reaction were carried out with I_2 (2 molar amounts), $NaHCO_3$ (2 molar amounts), and $Ce(SO_4)_2 \cdot 4H_2O$ (1 molar amount) in H_2O/solvent at room temperature. b) Without $NaHCO_3$.

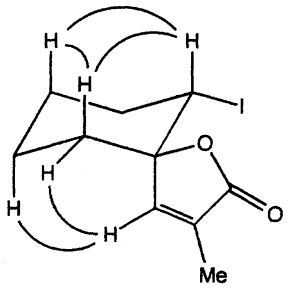
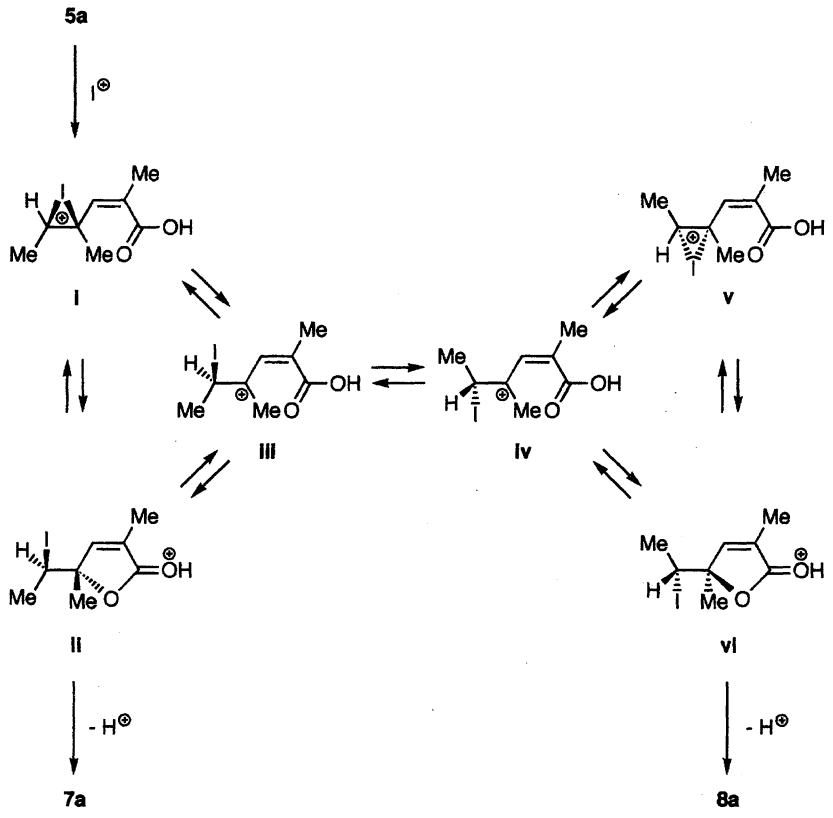


Fig. 1.



Scheme 6.

and **iv**, through which other isomers **v** and **vi** are also in equilibrium. Deprotonation from **vi** gives the other isomer of the product **8a**. Cyclohexane ring of **5b** prevents rotation of γ,δ-bond corresponding between **iii** and **iv**, which explains the stereoselective formation of **7b**.

In conclusion, iodolactonization of substituted $\alpha,\beta:\gamma,\delta$-unsaturated acid was successfully done by I_2 in MeCN or $I_2/NaHCO_3/CHCl_3/H_2O$ in the presence of cerium(IV) salt. Among a number of reports on iodolactonization reaction, in our knowledge, this is the first example in which two reaction sites, the C=C double bond and carboxylic acid, are conjugated with each other. Thus this study offers a new entry to iodolactones through intramolecular cyclization of $\alpha,\beta:\gamma,\delta$-unsaturated carboxylic acids without deconjugation. We could also clarify the difference between protolactonization and iodolactonization reactions regarding allylic silicon atom; i.e., protolactonization proceeds by the aid of trimethylsilyl group, while it prevents iodolactonization.

Experimental

General Procedures. Melting points were collected on a Laboratory Devices Mel-Temp apparatus. IR spectra were taken on a JASCO FT/IR-230 spectrometer. Both ^1H and ^{13}C NMR spectra were measured on a JEOL GSX-400 (400 MHz for ^1H; 100 MHz for ^{13}C) spectrometer. Chemical shifts are reported on the δ scale (ppm) with tetramethylsilane (Me_4Si = 0.00) or chloroform ($CHCl_3$ = 7.26 for ^1H; $CDCl_3$ = 77.0 for ^{13}C) as an internal standard. Both low-resolution mass spectra (MS) and high-resolution mass spectra (HRMS) were obtained on a JEOL SX-102A mass spectrometer with the EI method. Analytical TLC was done on coated TLC plates (Kieselgel 60 F254, layer thickness 0.2 mm). Wakogel C-200 or C-300 were used for column chromatography. Anhydrous Na_2SO_4 or $MgSO_4$ were used for drying of extracted organic layers.

Synthesis of the Substrates. See Ref. 4 for the preparation of **1a**. Compounds **5a** and **5b** were prepared by the following procedures.

Wittig Reaction. To a stirred suspension of NaH (1.79 g, 41.0 mmol; 55% in mineral oil, which was removed by washing with dry hexane) in dry dimethoxyethane (DME) (100 cm^3; distilled from CaH_2) was added dropwise ethyl 2-(diethoxyphosphinoyl)acetate $(EtO)_2P(O)CH_2CO_2Et$ (7.4 cm^3, 37 mmol) at 0 °C under Ar. After being stirred for 40 min, a solution of methyl iodide (2.85 cm^3, 44.8 mmol; 98% purity) in DME (40 cm^3) was added, and the resulting solution was heated to 70 °C for 4 h. This was cooled to 0 °C again, and then NaH (1.46 g, 33.5 mmol) was added. The stirring was continued at 0 °C for 1.5 h, a solution of (*E*)-2-methylbut-2-enal (3.0 cm^3, 31 mmol) in DME (60 cm^3) was added, and the mixture was stirred at room temperature overnight. The reaction was quenched by the addition of aqueous NH_4Cl, and the mixture was extracted with Et_2O and dried. Evaporation of the solvent followed by silica gel (12 g) column chromatography using hexane–Et_2O (98 : 2) as eluent to afford **6a** (2.31 g, 44%).

The same Wittig reaction of cyclohex-1-enecarbaldehyde (1.18 g) produced **6b** (940.1 mg, 45%) as a single diastereomer.

Ethyl 2,4-Dimethylhexa-2,4-dienoate (6a). An oil; IR (neat) 1705 (C=O), 1625 (C=C), and 1255 cm^{-1} (C–O); ^1H NMR ($CDCl_3$; $CHCl_3$ = 7.26); For the major isomer: δ = 1.31 (3H, t, *J* = 7 Hz, $OCH_2C\underline{H}_3$), 1.74 (3H, d, *J* = 7 Hz, C=CHC$\underline{H}_3$), 1.83 (3H, s, C=C-(CO_2Et)C$\underline{H}_3$), 1.99 (3H, s, C=C(CH_3)C=C), 4.21 (2H, q, *J* = 7 Hz, $OC\underline{H}_2CH_3$), 5.71 (1H, q, *J* = 7 Hz, C=C$\underline{H}$CH$_3$), and 7.11 (1H, s, C$\underline{H}$=CCO_2Et); For the minor isomer: δ = 1.28 (3H, t, *J* = 7 Hz, $OCH_2C\underline{H}_3$), 1.54 (3H, d, *J* = 7 Hz, C=CHC$\underline{H}_3$), 1.81 (3H, s, C=C(CO_2Et)C$\underline{H}_3$), 1.81 (3H, s, C=C(CH_3)C=C), 4.17 (2H, q, *J* = 7 Hz, $OC\underline{H}_2CH_3$), 5.47 (1H, q, *J* = 7 Hz, C=C$\underline{H}$CH$_3$), and 7.13 (1H, s, C$\underline{H}$=CCO_2Et); ^{13}C NMR ($CDCl_3$; Me_4Si = 0.0) δ = 14.0, 14.0, 14.1, 14.3, 14.3, 15.0, 16.0, 22.9, 60.6, 60.6, 124.9, 125.3, 128.0, 130.8, 132.2, 133.2, 138.8, 143.0, 168.5, and 169.3 (for both isomers; assignment was not made); MS *m/z* (rel intensity) 168 (M^+; 100), 153 (76), 125 (91), and 95 (72). HRMS [Found: *m/z* 168.1189 (M^+). Calcd for $C_{10}H_{16}O_2$: M, 168.1151].

Ethyl 3-(Cyclohex-1-en-1-yl)-2-methylprop-1-enoate (6b). An oil; IR (neat) 1705 (C=O), 1625 (C=C), and 1250 cm^{-1} (C–O); ^1H NMR ($CDCl_3$; Me_4Si = 0.00) δ = 1.30 (3H, t, *J* = 7 Hz, $OCH_2C\underline{H}_3$), 1.56—1.71 (4H, m), 2.01 (3H, d, *J* = 0.5 Hz, C=CCH$_3$), 2.14—2.26 (4H, m), 4.20 (2H, q, *J* = 7 Hz, $OC\underline{H}_2CH_3$), 5.92 (1H, br s, C$\underline{H}$=CCH=CCO_2Et), and 7.06 (1H, br s, C$\underline{H}$=CCO_2Et); ^{13}C NMR ($CDCl_3$; Me_4Si = 0.0) δ = 14.1, 14.3, 21.8, 22.7, 26.0, 28.6, 60.6, 124.9, 133.6, 135.0, 141.8, and 169.3; MS *m/z* (rel intensity) 194 (M^+; 100), 186 (36), 165 (61), 147 (42), 121 (56), 105 (39), 91 (59), and 79 (53). HRMS [Found: *m/z* 194.1271 (M^+). Calcd for $C_{12}H_{18}O_2$: M, 194.1307].

Hydrolysis. Compound **6a** (1.150 g, 6.836 mmol) was dissolved in a mixed solvent of MeOH (100 cm^3) and H_2O (80 cm^3), and to this was added KOH aq (40 cm^3; 1 mol dm^{-3} solution) with stirring. After this was heated to 95 °C for 35 min, HCl aq (1 mol dm^{-3}) was added to pH 3. Saturated NaCl aq was added, and the mixture was extracted with Et_2O and dried. Evaporation of the solvent followed by silica gel (25 g) column chromatography using hexane–Et_2O (9:1) as eluent afforded **5a** (851.7 mg, 89%).

Similarly, **6b** (49.6 mg) was hydrolyzed to afford **5b** (30.0 mg, 71%).

2,4-Dimethylhexa-2,4-dienoic Acid (5a). An oil; IR (neat) 2300—3500 (OH) and 1685 cm^{-1} (C=O); ^1H NMR ($CDCl_3$; Me_4Si = 0.00); For (2*E*)-isomer: δ = 1.77 (3H, br d, *J* = 7 Hz, C=CHC$\underline{H}_3$), 1.87 (3H, br s, C=C(CH_3)C=C), 2.02 (3H, br s, C=C-(CO_2H)C$\underline{H}_3$), 5.80 (1H, br q, *J* = 7 Hz, C=C$\underline{H}$CH$_3$), and 7.27 (1H, br s, C$\underline{H}$=CCO_2H); For (2*Z*)-isomer: δ = 1.58 (3H, br d, *J* = 7 Hz, C=CHC$\underline{H}_3$), 1.84 (3H, m, C=C(CH_3)C=C), 1.85 (3H, d, *J* = 1.5 Hz, C=C(CO_2H)C$\underline{H}_3$), 5.53 (1H, br q, *J* = 7 Hz, C=C$\underline{H}$CH$_3$), and 7.32 (1H, br s, C$\underline{H}$=CCO_2H); ^{13}C NMR ($CDCl_3$ = 77.0) For (2*E*)-isomer: δ = 13.5, 14.1, 15.8, 123.7, 132.7, 133.2, 145.5, and 175.0; For (2*Z*)-isomer: δ = 13.7, 15.0, 22.7, 126.6, 127.0, 132.0, 141.0, and 174.2; MS *m/z* (rel intensity) 139 ($M^+ - H$; 38), 124 (100), 94 (23), and 79 (25). HRMS [Found: *m/z* 139.0767 ($M^+ - H$). Calcd for $C_8H_{11}O_2$: M, 139.0759].

3-(Cyclohex-1-en-1-yl)-2-methylprop-1-enoic Acid (5b). Mp 93—96 °C; IR (Nujol®) 2500—3500 (OH) and 1685 cm^{-1} (C=O); ^1H NMR ($CDCl_3$; Me_4Si = 0.00) δ = 1.57—1.71 (4H, m), 2.02 (3H, s, CH_3), 2.16—2.30 (4H, m), 6.00 (1H, br s, C$\underline{H}$=CCH=CCO_2H), and 7.20 (1H, s, C$\underline{H}$=CCO_2H); double bond was found to be *E*-form from NOESY signal between methyl group (δ = 2.02) and ring protons (δ = 2.16—2.30 and 7.20); ^{13}C NMR ($CDCl_3$; Me_4Si = 0.0) δ = 13.7, 21.7, 22.7, 26.2, 28.4, 123.6, 135.1, 135.6, 144.4, and 174.9; MS *m/z* (rel intensity) 166 (M^+; 61), 121 (59), 111 (100), and 79 (72); HRMS [Found: *m/z* 166.1031 (M^+). Calcd for $C_{10}H_{14}O_2$: M, 166.0994].

Iodolactonization Reaction. Method A. In a 30 cm^3 round-bottomed flask was mixed **5a** (24.9 mg, 0.178 mmol), $NaHCO_3$ (29.1 mg), H_2O (0.64 cm^3), and $CHCl_3$ (2.5 cm^3) with stirring. After cooling in an ice bath, I_2 (91.2 mg, 0.359 mmol) was added, and the mixture was stirred at room temperature for 48 h. An

aqueous solution of $Na_2S_2O_3$ (10%) was added, and the organic layer was separated. The aqueous layer was extracted with CH_2Cl_2, and the combined organic layer was dried. Evaporation of the solvent followed by silica gel (2 g) column chromatography using hexane–AcOEt (94:6 and 90:10) as eluent afforded a mixture of **7a** and **8a** (14.4 mg, 30%; Entry 1 of Table 1). While by adding $Ce(SO_4)_2 \cdot 4H_2O$ (61.0 mg), **5a** (20.8 mg) afforded **7a/8a** (27.0 mg, 68%; Entry 5 of Table 1).

Similarly, **5b** (20.3 mg) yielded **7b** (22.9 mg, 64%; Entry 14 of Table 1) by adding $Ce(SO_4)_2 \cdot 4H_2O$ (50.0 mg).

Method B. Compound **5a** (12.7 mg, 0.0907 mmol) was dissolved in a solution of I_2(71.5 mg, 0.288 mmol) in MeCN (4.7 cm^3) at 0 °C. After being stirred for 30 min, the mixture was warmed to room temperature and the stirring was continued for 30 min. Saturated $NaHCO_3$ aq was added, and the mixture was extracted with Et_2O. The ethereal layer was washed with 10% $Na_2S_2O_3$ aq, H_2O, and saturated NaCl aq. Drying and evaporation of the solvent gave an oily residue, which was chromatographed on silica gel (3 g) using pentane–Et_2O (9:1) as eluent to afford **7a/8a** (17.8 mg, 74%).

Similarly, **5b** (22.6 mg) afforded **7b** (20.4 mg, 51%); **1a** (19.7 mg, 0.093 mmol) afforded **4** (2.7 mg, 11%).

5-(1-Iodoethyl)-5-methyl-3-methylenetetrahydrofuran-2-one (4). An oil; IR (neat) 1770 cm^{-1} (C=O); ^1H NMR ($CDCl_3$; $CHCl_3$ = 7.26) δ = 1.59 (3H, s, Me), 1.97 (3H, d, J = 7 Hz, CHMe), 2.84 (1H, dt, J = 17, 2.5 Hz, C=CCHH), 3.05 (1H, dt, J = 17, 3 Hz, C=CCHH), 4.26 (1H, q, J = 7 Hz, CHI), 5.69 (1H, t, J = 2.5 Hz, C=CHH), and 6.28 (1H, t, J = 3 Hz, C=CHH); ^{13}C NMR ($CDCl_3$ = 77.0) 22.4 (CH_3), 23.1 (CH_3), 34.4 (CH), 40.9 (CH_2), 84.4 (C), 123.1 (CH_2), 135.2 (C), and 169.1 (CO); MS *m/z* (rel intensity) 266 (M^+; 10), 139 (100), 111 (68), and 43 (60). HRMS [Found: *m/z* 265.9834 (M^+). Calcd for $C_8H_{11}O_2I$: M, 265.9804].

5-(1-Iodoethyl)-3,5-dimethylfuran-2(5*H*)-one (7a and 8a). Mp 52—55 °C; IR (neat) 1760 cm^{-1} (C=O); ^1H NMR ($CDCl_3$; Me_4Si = 0.00); For one isomer: δ = 1.62 (3H, s, Me), 1.93 (3H, d, J = 1.5 Hz, C=CMe), 1.98 (3H, d, J = 7 Hz, CHMe), 4.11 (1H, q, J = 7 Hz, CHI), and 7.22 (1H, q, J = 1.5 Hz, C=CH); For the other isomer: δ = 1.68 (3H, s, Me), 1.84 (3H, d, J = 7 Hz, CHMe), 1.95 (3H, d, J = 1.5 Hz, C=CMe), 4.25 (1H, q, J = 7 Hz, CHI), and 7.15 (1H, q, J = 1.5 Hz, C=CH); ^{13}C NMR ($CDCl_3$ = 77.0) δ = 10.6, 10.6, 20.1, 22.9, 23.8, 23.9, 29.5, 30.0, 86.7, 86.9, 130.5, 131.1, 151.0, 152.6, 172.7, and 172.9 (for both isomers; assignment was not made); MS *m/z* (rel intensity) 266 (M^+; 7), 139 (100), 111 (66), and 43 (77). HRMS [Found: *m/z* 265.9815 (M^+). Calcd for $C_8H_{11}IO_2$: M, 265.9804].

6-Iodo-3-methyl-1-oxaspiro[4.5]dec-3-en-2-one (7b). Mp 99—100 °C; IR (Nujol®) 1760 cm^{-1} (C=O); ^1H NMR ($CDCl_3$; Me_4Si = 0.00) δ = 1.51—1.79 (4H, m, 8-H_2, 9-H, 10-H), 1.86 (1H, m, 9-H), 1.95 (3H, d, J = 1.5 Hz, Me), 2.05 (1H, m, 7-H), 2.22 (1H, m, 10-H), 2.36 (1H, ddt, J = 8, 14, 4 Hz, 7-H), 4.31 (1H, dd, J = 4, 8 Hz, 6-H), and 7.24 (1H, q, J = 1.5 Hz, 4-H) (detailed assignment of the signals were done by COSY spectrum); NOESY signal was observed as illustrated in Fig. 1; ^{13}C NMR ($CDCl_3$ = 77.0) δ = 10.7, 22.6, 24.1, 32.5, 35.0, 35.3, 86.1, 131.2, 152.1, and 172.4; MS *m/z* (rel intensity) 292 (M^+; 10), 166 (100), 137 (64), 91 (86), and 55 (89). HRMS [Found: *m/z* 291.9980 (M^+). Calcd for $C_{10}H_{13}IO_2$: M, 291.9961].

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