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Formation of Tetrahydrofuran Derivatives and Acetonylation of Alkenes Using Carbon Radicals Derived from Manganese(III) Oxidation of Diketene

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Oxidation of a mixture of diketene and a 1,1-diarylethene **1** with manganese(III) acetate dihydrate gave an equilibrium mixture of 5-hydroxy-2-pentanone **2** and a tetrahydrofuran-2-ol, which was subsequently dehydrated in glacial acetic acid to yield 4-penten-2-one **4** in good yield. A similar reaction in the presence of alcohols or amines afforded 2-alkoxy-2-methyltetrahydrofurans **5** or 3-acetyl-2-aminodihydrofurans **9** in moderate yields. Diketene reacted with manganese(III) acetate in the presence of nucleophiles, such as water and alcohols, to give a mixture of unconjugated manganese(III) enolate **A** and conjugated manganese(III) enolate **B**. Major products **4** and **5** were formed by the oxidation of the conjugated manganese(III) enolate **B**. Tetrahydrofurylideneacetates **3** and **7** derived from the unstable unconjugated enolate **A** were also obtained as minor products. The reaction pathways are discussed.

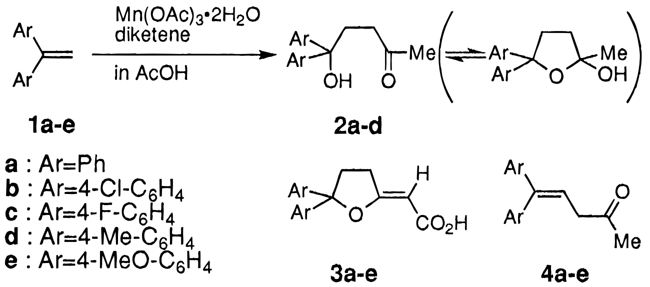
Introduction

Diketene is a versatile reagent for the preparation of acetoacetic acid derivatives and is broadly useful in organic synthesis.[1−5] However, few reports exist for the generation of radicals from diketene except for the VO(OR)Cl_2-induced oxidation of diketene.[6] Diketene has a rather strained *exo*-methyleneoxetanone structure, and it was thought that diketene might be sensitive toward other oxidants. Manganese(III) acetate is well-known as a mild one-electron oxidant that leads to dicarbonylmethyl radicals, •CH(COR)COR′, from 1,3-dicarbonyl compounds.[7−9] We believed that radicals would be formed by manganese(III) oxidation of diketene since diketene is an analogue of 1,3-dicarbonyl compounds in the presence of nucleophiles. Accordingly, we examined the oxidation of diketene with manganese(III) acetate dihydrate ($Mn(OAc)_3{\cdot}2H_2O$) in the presence of a 1,1-diarylethene and the absence or presence of a nucleophile.

Results and Discussion

Oxidation of a Mixture of 1,1-Diarylethenes and Diketene. Reaction of 1,1-diphenylethene (**1a**), diketene, and $Mn(OAc)_3{\cdot}2H_2O$ in glacial acetic acid at 23 °C for 16 h provided **2a** (5%) and **3a** (7%) without the formation of any γ-lactone[10] or 1,2-dioxan-3-ol[11] (Scheme 1 and Table 1, entry 1). Although the NMR spectrum of **2a** in DMSO-d_6 showed signals of a single compound, it gradually formed an equilibrium mixture of 5-hydroxy-5,5-diphenyl-2-pentanone (**2a**) and 2-methyl-5,5-diphenyl-

Scheme 1



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[⊗] Abstract published in *Advance ACS Abstracts*, October 1, 1996.

(1) Clemens, R. J. *Chem. Rev.* **1986**, *86*, 241.

(2) Lawesson, S.-O.; Gronwall, S.; Sandberg, R. *Organic Syntheses*; Wiley: New York, 1973; Collect. Vol. V, p 155.

(3) Vedejs, E.; Bennett, N. S.; Conn, L. M.; Diver, S. T.; Gingras, M.; Oliver, P. A.; Peterson, M. J. *J. Org. Chem.* **1993**, *58*, 7286.

(4) Shibata, I.; Nishio, M.; Baba, A.; Matsuda, H. *Chem. Lett.* **1993**, 1219; *J. Chem. Soc., Chem. Commun.* **1993**, 1067.

(5) (a) Baldwin, S. W.; Wilkinson, J. M. *J. Am. Chem. Soc.* **1980**, *102*, 3634. (b) Takeshita, H.; Cui, Y.-S.; Kato, N.; Mori, A. *Bull. Chem. Soc. Jpn.* **1993**, *66*, 2694.

(6) Hirao, T.; Fujii, T.; Ohshiro, Y. *J. Organomet. Chem.* **1991**, *407*, C1.

(7) For recent reviews see: (a) Badanyan, Sh. O.; Melikyan, G. G.; Mkrtchyan, D. A. *Russ. Chem. Rev.* **1989**, *58*, 286; *Usp. Khim.* **1989**, *58*, 475. (b) Melikyan, G. G. *Synthesis* **1993**, 833. (c) Iqbal, J.; Bhatia, B.; Nayyar, N. K. *Chem. Rev.* **1994**, *94*, 519. (d) Snider, B. B. *Chem. Rev.* **1996**, *96*, 339.

(8) (a) Heiba, E. I.; Dessau, R. M. *J. Org. Chem.* **1974**, *39*, 3456. (b) Ito, N.; Nishino, H.; Kurosawa, K. *Bull. Chem. Soc. Jpn.* **1983**, *56*, 3527. (c) Corey, E. J.; Kang, M.-C. *J. Am. Chem. Soc.* **1984**, *106*, 5384. (d) Nishino, H. *Bull. Chem. Soc. Jpn.* **1985**, *58*, 217. (e) Fristad, W. E.; Hershberger, S. S. *J. Org. Chem.* **1985**, *50*, 1026. (f) Snider, B. B.; Moham, R.; Kates, S. A. *J. Org. Chem.* **1985**, *50*, 3659. (g) Fujimoto, N.; Nishino, H.; Kurosawa, K. *Bull. Chem. Soc. Jpn.* **1986**, *59*, 3161. (h) Sato, H.; Nishino, H.; Kurosawa, K. *Bull. Chem. Soc. Jpn.* **1987**, *60*, 1753. (i) Yang, F. Z.; Trost, M. K.; Fristad, W. E. *Tetrahedron Lett.* **1987**, *28*, 1493. (j) Snider, B. B.; Moham, R.; Kates, S. A. *Tetrahedron Lett.* **1987**, *28*, 841. (k) Moham, R.; Kates, S. A.; Dombroski, M. A.; Snider, B. B. *Tetrahedron Lett.* **1987**, *28*, 845. (l) Snider, B. B.; Dombroski, M. A. *J. Org. Chem.* **1987**, *52*, 5487. (m) Snider, B. B.; Patricia, J. J.; Kates, S. A. *J. Org. Chem.* **1988**, *53*, 2137. (n) Snider, B. B.; Patricia, J. J. *J. Org. Chem.* **1989**, *54*, 38. (o) Citterio, A.; Fancelli, D.; Finzi, C.; Pesce, L. *J. Org. Chem.* **1989**, *54*, 2713. (p) Snider, B. B.; Merritt, J. E.; Dombroski, M. A.; Buckman, B. O. *J. Org. Chem.* **1991**, *56*, 45544. (q) Nishino, H.; Kamachi, H.; Baba, H.; Kurosawa, K. *J. Org. Chem.* **1992**, *57*, 3551. (r) Snider, B. B.; Zhang, Q.; Dombroski, M. A. *J. Org. Chem.* **1992**, *57*, 4195 and references cited therein.

(9) (a) Nishino, H.; Hashimoto, H,; Korp, J. D.; Kurosawa, K. *Bull. Chem. Soc. Jpn.* **1995**, *68*, 1999. (b) Nishino, H.; Ishida, K.; Hashimoto, H.; Kurosawa, K. *Synthesis* **1996**, 888.

(10) (a) Bush, J. B.; Finkbeiner, H. *J. Am. Chem. Soc.* **1968**, *90*, 5903. (b) Heiba, E. I.; Dessau, R. M.; Koehl, W. J., Jr. *J. Am. Chem. Soc.* **1968**, *90*, 5905. (c) Okano, M. *Chem. Lett.* **1973**, 165. (d) Heiba, E. I.; Dessau, R. M.; Rodewald, P. G. *J. Am. Chem. Soc.* **1974**, *96*, 7977. (e) Fristad, W. E.; Peterson, J. R. *J. Org. Chem.* **1985**, *50*, 10. (f) Fristad, W. E.; Peterson, J. R.; Ernst, A. B. *J. Org. Chem.* **1985**, *50*, 3143. (g) Ernst, A. B.; Fristad, W. E. *Tetrahedron Lett.* **1985**, *26*, 3761. (h) Corey, E. J.; Gross, A. W. *Tetrahedron Lett.* **1985**, *26*, 4291. (i) Fristad, W. E.; Peterson, J. R.; Ernst, A. B.; Urbi, G. B. *Tetreahedron* **1986**, *42*, 3429.

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Table 1. Manganese(III) Oxidation of a Mixture of 1,1-Diarylthenes 1a−e and Diketene[a]

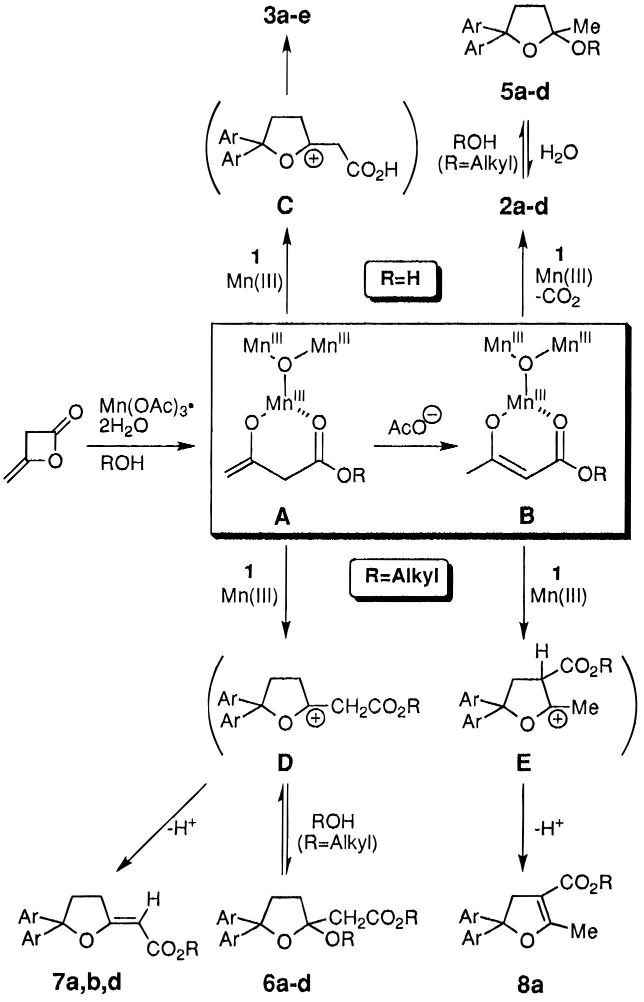
entry	ethene	molar ratio[b]	T (°C)	time (min)	product (yield/%)[c]		
1	**1a**	1:4:1.5	23	16 h	**2a** (5)	**3a** (7)	
2	**1a**	1:4:4	reflux	1	**2a** (40)	**3a** (6)	**4a** (25)
3	**1a**	1:4:4	reflux	10			**4a** (54)
4[d]	**1a**	1:4:4	80	60	**2a** (41)		
5	**1b**	1:4:4	80	3	**2b** (30)	**3b** (9)	
6	**1b**	1:4:4	reflux	20			**4b** (58)
7	**1c**	1:4:4	reflux	1	**2c** (15)	**3c** (3)	**4c** (14)
8	**1c**	1:4:4	reflux	20			**4c** (52)
9	**1d**	1:4:4	65	20	**2d** (14)	**3d** (12)	
10	**1d**	1:4:4	reflux	1			**4d** (50)
11[e]	**1d**	1:4:6.5	reflux	3			**4d** (79)
12	**1e**	1:4:4	45	60		**3e** (5)	**4e** (10)
13[e]	**1e**	1:4:4	reflux	3			**4e** (25)

[a] The reaction was carried out in glacial acetic acid (10mL) until the dark-brown color of Mn(III) disappeared. [b] Ethene:diketene: $Mn(OAc)_3 \cdot 2H_2O$. [c] Isolated yield based on the amount of the ethene used. [d] Water (100 equiv) was added to the reaction mixture. [e] The reaction was performed under argon atmosphere.

tetrahydrofuran-2-ol upon standing in acetic acid or deuteriochloroform. The structure of **3a** was determined to be 2(*Z*)-(carboxymethylene)-5,5-diphenyltetrahydrofuran on the basis of the spectroscopic data and elemental analysis. Although the yields are poor, the formation of **3a** provides convincing evidence for the formation of $^{\bullet}CH_2COCH_2COOH$ from unconjugated manganese(III) enolate **A** as shown in Scheme 2. In order to improve the yield of **2a** and **3a**, the reaction was performed at elevated temperatures. When the reaction mixture was stirred in refluxing acetic acid until the dark-brown color of Mn(III) disappeared (1 min), the yield of **2a** increased to 40%, while the yield of **3a** remained almost unchanged (Table 1, entry 2). When heating was continued after the oxidation was finished (10 min), only **4a** was obtained in good yield (Table 1, entry 3). Addition of water, to accelerate the decomposition of diketene, had no effect on the yield of **2a** (Table 1, entry 4). To our surprise, in addition to **2a** and **3a**, 5,5-diphenyl-4-penten-2-one (**4a**) was formed. A similar oxidation of 1,1-diarylethenes **1b**−**e** gave **2b**−**d**, **3b**−**e**, and **4b**−**e** (Table 1, entries 5, 7, 9, and 12). Prolonged heating resulted in the formation of 4-penten-2-ones **4b**−**d** (Table 1, entries 6 and 8). Reaction of **1d** under inert gas led to **4d** in the maximum yield (Table 1, entry 11). The reaction of **1e** gave an intractable mixture and **3e** and **4e**, which were isolated in low yield.

Oxidation of a Mixture of 1,1-Diarylethenes and Diketene in the Presence of Alcohols. In order to obtain 2-alkoxytetrahydrofurans, similar reactions were conducted in the presence of alcohols under various reaction conditions. The oxidation of **1a** using 200 equiv of ethanol under an argon atmosphere at 23 °C gave 2-ethoxy-2-methyl-5,5-diphenyltetrahydrofuran (**5a**, R = Et) in moderate yield along with small amounts of **2a** and 2-[(ethoxycarbonyl)methyl]-2-ethoxy-5,5-diphenyltetrahydrofuran (**6a**, R = Et) (Scheme 2 and Table 2, entry 14). When the same oxidation was done at reflux, similar products were obtained together with small amounts of **3a**, 2-[(ethoxycarbonyl)methylene]-5,5-diphenyltetrahydrofuran (**7a**, R = Et), and 3-(ethoxycarbonyl)-2-methyl-5,5-diphenyl-4,5-dihydrofuran (**8a**, R = Et) (Table 2, entry 15). The reactions with other alkenes **1b**−**d** under similar conditions also afforded **5b**−**d** (R = Et) in moderate yields (Table 2, entries 16−19). Use of other alcohols such as methanol, 1-propanol, 2-propanol, 1-butanol, and 2-butanol in the oxidation of **1a** resulted in complicated reaction mixtures (Table 2, entries 21−25). 1-Propanol and 1-butanol were introduced in tetrahydrofuran to give the corresponding **5a** (R = Pr and Bu) (Table 2, entries 22 and 24), but it was difficult to substitute 2-propanol and 2-butanol into the tetrahydrofuran ring (Table 2, entries 23 and 25).

Scheme 2



Manganese(III) Oxidation of a Mixture of 1,1-Diarylthenes 1a−e and Diketene in the Presence of Amines. Using amines as nucleophiles in the present oxidation should lead to manganese(III) enolates **F** and **G**, which should react with 1,1-diarylethenes in acetic acid to give 3-carboxamido-5,5-diaryl-2-methyl-4,5-dihydrofurans **11a** (R = Bu or Bn) (Scheme 3 and Table 3, entries 26 and 29). On the other hand, when an aprotic solvent was used, such as acetonitrile, which is not a typical solvent for manganese(III) oxidations,[8p] similar reactions took place that produced mainly 3-acetyl-2-amino-5,5-diaryl-4,5-dihydrofurans **9a**−**d** (R = Bu, *t*-Bu, or Bn) (Table 3, entries 27, 28, and 30−33).

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(11) (a) Tategami, S.; Yamada, T.; Nishino, H.; Korp, J. D.; Kurosawa, K. *Tetrahedron Lett.* **1990**, *31*, 6371. (b) Nishino, H.; Tategami, S.; Yamada, T.; Korp, J. D.; Kurosawa, K. *Bull. Chem. Soc. Jpn.* **1991**, *64*, 1800. (c) Qian, C.-Y.; Nishino, H.; Kurosawa, K. *Bull. Chem. Soc. Jpn.* **1991**, *64*, 3557. (d) Qian, C.-Y.; Yamada, T.; Nishino, H.; Kurosawa, K. *Bull. Chem. Soc. Jpn.* **1992**, *65*, 1371. (e) Yamada, T.; Iwahara, Y.; Nishino, H.; Kurosawa, K. *J. Chem. Soc., Perkin Trans. 1* **1993**, 609. (f) Qian, C.-Y.; Nishino, H.; Kurosawa, K. *J. Heterocycl. Chem.* **1993**, *30*, 209. (g) Ouyang, J.; Nishino, H.; Kurosawa, K. *J. Heterocycl. Chem.* **1995**, *32*, 1783. (h) Nguyen, V.-H.; Nishino, H.; Kurosawa, K. *Tetrahedron Lett.* **1996**, *37*, in press.

Table 2. Manganese(III) Oxidation of a Mixture of 1,1-Diarylthene 1a–e and Diketene in the Presence of Alcohols[a]

entry	ethene	alcohol	R	product (yield/%)[b]					
14[c]	**1a**	EtOH	Et	**2a** (4)		**5a** (50)	**6a** (11)		
15	**1a**	EtOH	Et	**2a** (8)	**3a** (4)	**5a** (48)		**7a** (6)	**8a** (3)
16	**1b**	EtOH	Et	**2b** (4)	**3b** (4)	**5b** (52)	**6b** (9)	**7b** (4)	
17	**1c**	EtOH	Et	**2c** (12)	**3c** (3)	**5c** (40)	**6c** (10)		
18[c,d]	**1d**	EtOH	Et	**2d** (17)	**5d** (42)	**6d** (12)			
19	**1d**	EtOH	Et		**3d** (7)	**5d** (46)		**7d** (15)	
20[c]	**1e**	EtOH	Et		**3e** (3)				
21	**1a**	MeOH	Me	**2a** (16)	**3a** (2)	**5a** (17)	**6a** (22)	**7a** (7)	
22	**1a**	PrOH	Pr	**2a** (14)		**5a** (42)	**6a** (6)	**7a** (5)	
23	**1a**	*i*-PrOH	*i*-Pr	**2a** (40)	**3a** (3)	**5a** (8)		**7a** (6)	**8a** (6)
24	**1a**	BuOH	Bu	**2a** (6)		**5a** (30)	**6a** (6)	**7a** (7)	**8a** (3)
25	**1a**	*s*-BuOH	*s*-Bu	**2a** (34)	**3a** (5)	**5a** (4)		**7a** (5)	**8a** (5)

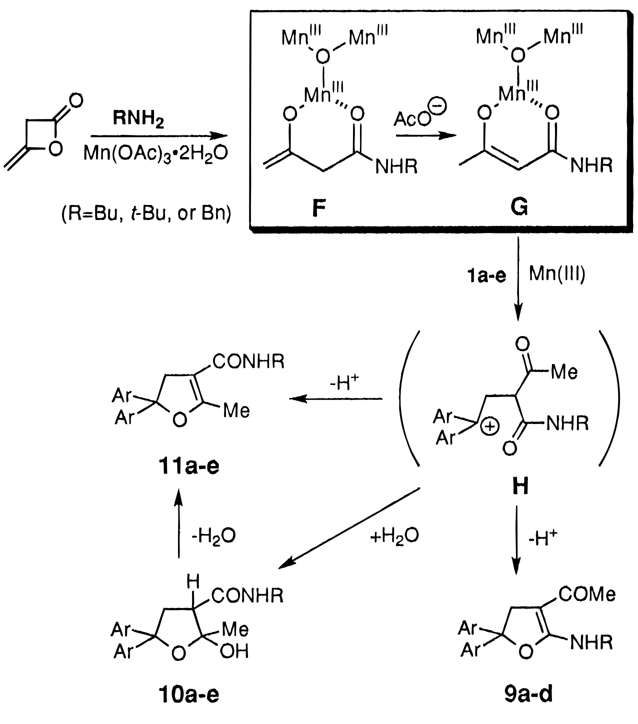
[a] The reaction was carried out at the molar ratio of ethene:diketene:$Mn(OAc)_3\cdot 2H_2O$:alcohol = 1:4:4:200 in boiling glacial acetic acid (10 mL) for 3 min under argon atmosphere. [b] Isolated yield based on the amount of the ethene used. [c] The reaction was performed at 23 °C for 16 h under argon atmosphere. [d] The reaction was carried out at the molar ratio of **1d**:diketene:$Mn(OAc)_3\cdot 2H_2O$:ethanol = 1:4:6:200.

Table 3. Manganese(III) Oxidation of a Mixture of 1,1-Diarylthene 1a–e and Diketene in the Presence of Amines[a]

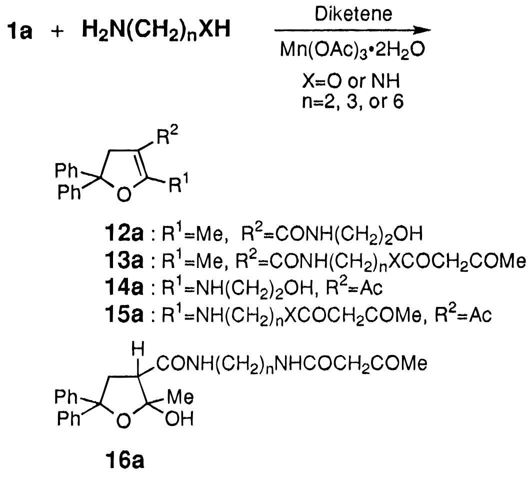
entry	ethene	amine	solvent	time (min)	R	product (yield/%)[b]		
26	**1a**	$BuNH_2$	AcOH	3	Bu			**11a** (30)
27	**1a**	$BuNH_2$	MeCN	20	Bu	**9a** (34)	**10a** (21)	**11a** (6)
28	**1a**	*t*-$BuNH_2$	MeCN	40	*t*-Bu	**9a** (47)	**10a** (18)	**11a** (14)
29	**1a**	$BnNH_2$	AcOH	3	Bn			**11a** (28)
30	**1a**	$BnNH_2$	MeCN	40	Bn	**9a** (35)	**10a** (15)	**11a** (16)
31	**1b**	*t*-$BuNH_2$	MeCN	15	*t*-Bu	**9b** (42)	**10b** (21)	**11b** (6)
32	**1c**	*t*-$BuNH_2$	MeCN	15	*t*-Bu	**9c** (37)	**10c** (15)	**11c** (6)
33	**1d**	*t*-$BuNH_2$	MeCN	10	*t*-Bu	**9d** (33)	**10d** (26)	**11d** (10)
34[c]	**1e**	*t*-$BuNH_2$	MeCN	20	*t*-Bu		**10e** (48)	**11e** (20)

[a] The reaction was carried out at the molar ratio of ethene:diketene:$Mn(OAc)_3\cdot 2H_2O$:amine = 1:4:3:4 at reflux temperature in a solvent (15 mL) until the dark-brown color of Mn(III) disappeared. [b] Isolated yield based on the amount of the ethene used. [c] The reaction was performed at 75 °C.

Scheme 3



Scheme 4



The oxidation with **1a** using 2-aminoethanol was carried out in the hope of forming bis(4,5-dihydrofuran)s of which each dihydrofuran ring was connected to a carbon chain.[12] Unfortunately, the corresponding bis(dihydrofuran)s were not obtained in either acetic acid or acetonitrile solution. However, products **12a** and **13a** (X = O, *n* = 2) were formed in acetic acid, while in acetonitrile their isomers **14a** and **15a** (X = O, *n* = 2) were obtained (Scheme 4 and Table 4, entries 35 and 36). A similar reaction using 1,3-propanediamine or 1,6-hexanediamine also did not give bis(dihydrofuran)s, but amidodihydrofuran **13a** (X = NH, *n* = 3), aminodihydrofuran **15a** (X = NH, *n* = 3 or 6), and amidotetrahydrofuranol **16a** (*n* = 3 or 6) were isolated (Table 4, entries 37 and 38).

Reaction Pathways. The mechanism for the formation of radicals by a manganese(III) acetate-mediated oxidation system was well-documented by Fristad concerning acetic acid derivatives[10e,i] and Snider regarding 1,3-dicarbonyl esters.[7,8m] The former reported that the rate-determining step should be enolization of the acetic

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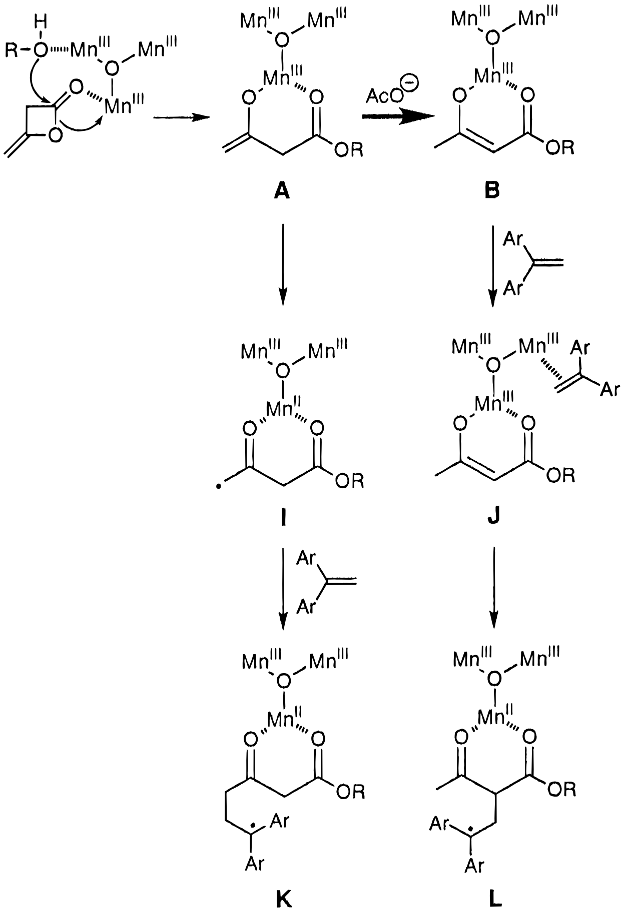
(12) Nishino, H.; Yoshida, T.; Kurosawa, K *Bull. Chem. Soc. Jpn.* **1991**, *64*, 1097.

Table 4. Manganese(III) Oxidation of a Mixture of 1,1-Diphenylethene (1a) and Diketene in the Presence of 2-Aminoethanol or Diamines

entry	X	n	molar ratio[a]	solvent	T (°C)	time (min)	product (yield/%)[b]		
35	O	2	1:3:4:3	AcOH	reflux	5	**12a** (24)	**13a** (14)	
36	O	2	1:4:4:4	MeCN	75	10	**14a** (22)	**15a** (25)	
37	NH	3	1:24:3:12	MeCN	75	30	**13a** (14)	**15a** (23)	**16a** (22)
38	NH	6	1:12:3:6	MeCN	75	30	**15a** (40)	**16a** (24)	

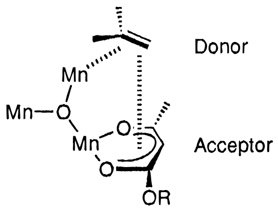
[a] **1a**:diketene:$Mn(OAc)_3{\cdot}2H_2O$:amine. [b] Isolated yield based on the amount of **1a** used.

Scheme 5



acid ligand. The latter concluded that the rate-determining step was also enolization in the case of 2-substituted 1,3-dicarbonyl esters. However, enolization of 2-unsubstituted 1,3-dicarbonyl esters is fast and reversible; therefore, the rate-determining step in the presence of an alkene must involve the alkene, since the reaction rate was much faster in its presence. In this present reaction, the corresponding unconjugated enolate **A** (R = H or alkyl) would be directly formed by the attack of water or other additives, such as alcohols, on the carbonyl carbon of diketene in the manganese(III) coordination sphere (Scheme 5). The enolate **A** could be expected to be easily converted to conjugated enolate **B** (R = H or alkyl), since the conjugated enolate **B** is more stable than unconjugated enolate **A**.

Scheme 6



When the oxidation was conducted at reflux temperature, in the absence of alkene, the reaction was complete within 1 min to give volatile compounds. Upon addition of ethanol, the reaction rate was similar, giving ethyl acetate as the main product. The formation of enolates **A** and **B** should be fast at higher temperature, and subsequent one-electron transfer should also be quick. However, the reaction in the absence of alkene at room temperature was quite slow and was not complete even after 2 days. Normally, the oxidation in the presence of an alkene was finished within 3 min at higher temperature. This meant that the rate-determining step must have involved the added alkene, as proposed by Snider[7,8m] and others.[13] When an alkene was added to the oxidation system, alkene–manganese(III) enolate complex **J** could have been formed from the conjugated enolate **B** (Scheme 5). The alkene and 1,3-dicarbonyl ligand should form an electron donor–acceptor-like complex[14] in the manganese(III) coordination sphere at this stage (Scheme 6), and one-electron transfer from the alkene to manganese(III) center *via* 1,3-dicarbonyl ligand may have occurred concertedly. As a result, manganese(III)-complexed radical **L** should have been produced. On the other hand, α-keto radical **I** could have been formed from the unconjugated manganese(III) enolate **A** as in the oxidation of 3-oxo-3-phenylpropanoic acid reported by Narasaka et al.[15] and unsaturated ketones reported by Snider and McCarthy Cole,[16] giving radical **K** (Scheme 5). Therefore, the product **3** could be produced from radical **K** (R = H) *via* cation **C** (Schemes 2 and 5), and the product **2** was obtained from radical **L** (R = H) *via* decarboxylation of β-keto acid **N** (Scheme 7).[17] Although the radical **L** (R = H) or cation **M** (R = H) might cyclize to afford γ-lactone,[15] γ-lactones were not detected. Prolonged heating of the reaction without any additives gave improved yields of **4** (Table 1, entries 4, 6, 8, 11, and 13). Heating products **2a** and **3a** in acetic acid for 10 min gave **4a** quantitatively, suggesting that this occurred in oxidations carried out at reflux (Scheme 7).

When the reaction was conducted in the presence of ethanol, a small amount of **2a**–**d** was still isolated (Table 2, entries 14–18). Since **2a**–**d** were in equilibrium with the corresponding tetrahydrofuranols in a protic solvent,

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(13) (a) Corey, E. J.; Kang, M.-C. *J. Am. Chem. Soc.* **1984**, *106*, 5384. (b) Vinogradov, M. G.; Dolinko, V. I.; Nikishin, G. I. *Bull. Acad. Sci. USSR, Div. Chem. Sci. (Engl. Transl.)* **1982**, 2036. (c) Vinogradov, M. G.; Kovalev, I. P.; Nikishin, G. I. *Bull. Acad. Sci. USSR, Div. Chem. Sci. (Engl. Transl.)* **1984**, 342. (d) Vinogradov, M. G.; Dolinko, V. I.; Nikishin, G. I. *Bull. Acad. Sci. USSR, Div. Chem. Sci. (Engl. Transl.)* **1984**, 1884.

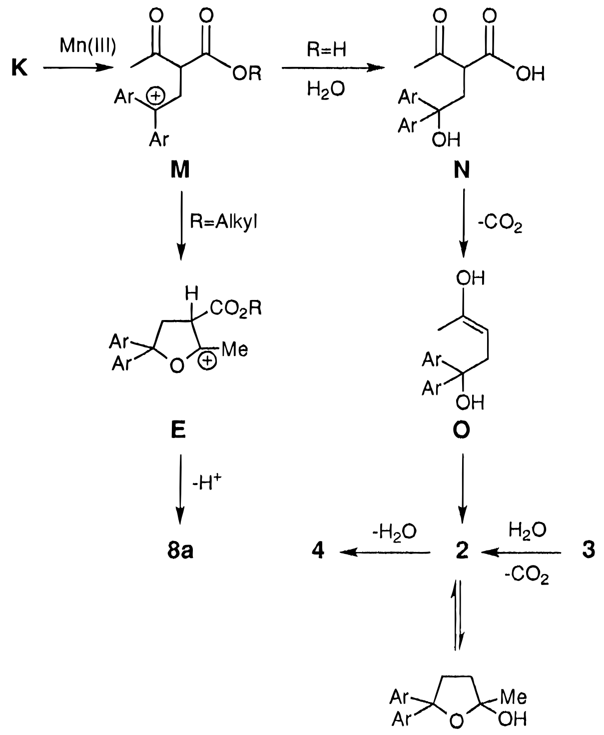
(14) Foster, R. E. *Charge-Transfer Complexes in Organic Chemistry*; Academic: New York, 1969.

(15) Narasaka, K.; Miyoshi, N.; Iwakura, K.; Okauchi, T. *Chem. Lett.* **1989**, 2169.

(16) Snider, B. B.; McCarthy Cole, B. *J. Org. Chem.* **1995**, *60*, 5376.

(17) (a) Swain, C. G.; Bader, R. F. W.; Estreve, R. M., Jr.; Griffin, R. N. *J. Am. Chem. Soc.* **1961**, *83*, 1951. (b) Logue, M. W.; Pollack, R. M.; Vitullo, V. P. *J. Am. Chem. Soc.* **1975**, *97*, 6868. (c) Oshry, L.; Rosenfeld, S. M. *Org. Prep. Proc. Int.* **1982**, *14*, 249.

Scheme 7



it was presumed that 2-ethoxytetrahydrofurans **5a**−**d** were formed by substitution of the hydroxyl group with ethanol. In fact, **2a** was easily converted in acetic acid at 80 °C for 10 min in the presence of ethanol to give **5a** quantitatively. Continuing to heat the mixture for 1 h gave **4a**. In addition, it was difficult to exchange the hydroxyl group of **2a** to bulky alkoxyl groups with 2-propanol and 2-butanol (Table 2, entries 23 and 25). These results suggested that the alkoxytetrahydrofurans **5** were also in equilibrium with pentanones **2** and tetrahydrofuranols in acetic acid (Scheme 2). Tetrahydrofurans **6** and **7** must have been produced from the intermediate carbocation **D** *via* the oxidation of radical **K** (R = alkyl). Likewise, isomerization of **A** (R = alkyl) led to the more stable conjugated enolate **B** (R = alkyl), and subsequent oxidation in the presence of an alkene yielded the dihydrofurans **8a** *via* cation **E** (Scheme 7).

In the presence of amines, the reaction did not give any products derived from the unconjugated enolate **F**, but amino- (**9**, **14**, and **15**) and carbamoylfuran derivatives (**10**, **11**, **12**, **13**, and **16**) were obtained (Schemes 3 and 4). Either the carbonyl oxygen of the acetyl or the amido group may be used to cyclize to the cation **H** as discussed in the manganese(III)-mediated oxidative cyclization of terminal alkadienes with malonamide or acetoacetamide.[9] Reaction in acetic acid preferentially afforded **11** since the ring closure on the carbamoyl oxygen might be strongly suppressed by the protonation of amide nitrogen of **H** (Table 3, entries 26 and 29). In addition, **10** would also be readily dehydrated under the conditions to give **11**.

Conclusion

We scrutinized the reaction of alkenes with manganese(III) acetate dihydrate in the presence of diketene and elucidated the acetonylation pathway *via* dehydration of an equilibrium mixture of 5-hydroxy-2-pentanones **2** and the 2-tetrahydrofuranols. When alcohols were added to the reaction mixture, the pentanones **2** were trapped as 2-alkoxytetrahydrofurans **5**. Addition of amines resulted in the formation of 2-amino-4,5-dihydrofurans **9**, when acetonitrile was used as the solvent. This is the first example of introduction of an amino group into the 2 position of the 4,5-dihydrofuran ring using manganese(III) oxidation. Although most products were derived from conjugated enolate **B**, minor products were also isolated from the unstable unconjugated enolate **A**.

Experimental Section

Measurements. Melting points are uncorrected. All of the ^{1}H and ^{13}C NMR spectra were recorded at 60 or 90 MHz for ^{1}H and 22.5 MHz for ^{13}C, respectively, with tetramethylsilane as the internal standard. The chemical shifts are shown in δ values (ppm). The IR spectral data are expressed in cm^{-1}. High resolution mass spectra were recorded at the Analytical Center of Kumamoto University, Kumamoto, Japan. Elemental analyses were performed at the Elemental Analysis Center of Kyushu University, Fukuoka, Japan.

Materials. Manganese(III) acetate dihydrate, $Mn(OAc)_3 \cdot 2H_2O$, was prepared according to the literature method.[12] 1,1-Diarylethenes **1a**−**e** were prepared by dehydration of the corresponding alcohols, which were synthesized from substituted acetophenones and arylmagnesium bromides.[8b,g,h,11b] Manganese(II) acetate tetrahydrate, diketene, methanol, ethanol, 1-propanol, 2-propanol, 1-butanol, 2-butanol, butylamine, *tert*-butylamine, benzylamine, 2-aminoethanol, 1,3-propanediamine, 1,6-hexanediamine, glacial acetic acid, and acetonitrile were purchased from Wako Pure Chemical Ind., Ltd., and were used as received.

Oxidation of a Mixture of 1,1-Diarylethenes and Diketene. 1,1-Diarylethene **1** (1 mmol) was weighed into a 50 mL flask equipped with a magnetic stirrer. Glacial acetic acid (10 mL) was added to the flask, which was placed in an appropriate temperature oil bath, and the mixture was stirred. Diketene (4 mmol) was added, immediately followed by addition of manganese(III) acetate (1.5−6.5 mmol). The flask was fitted with a reflux condenser (and a gas inlet tube, in the case of reaction carried out under argon atmosphere), and the reaction was allowed to proceed until the reaction mixture turned colorless or yellow. The solvent was removed *in vacuo*, and the residue was quenched with water. The aqueous mixture was extracted with chloroform. The extract was concentrated to dryness, and the products were separated on silica gel TLC (Wakogel B-10 or Merck Kieselgel 60 F_{254}) with diethyl ether/hexane (3:7 v/v) as the developing solvent. Solid products were further recrystallized by indicated solvent. The molar ratios, reaction times, and product yields are summarized in Table 1. Specfic details are given below.

Mixture of 2-methyl-5,5-diphenyltetrahydrofuran-2-ol and 5-hydroxy-5,5-diphenyl-2-pentanone (2a): 42:58 mixture in $CDCl_3$; colorless needles (from petroleum ether/hexane); mp 71−72 °C; IR ($CHCl_3$) ν 3650−3200, 1716; ^{1}H NMR ($CDCl_3$) δ 1.62 (3H, s), 2.05 (3H, s), 1.96−2.91 (8H, m), 7.1−7.6 (20H, m); ^{13}C NMR ($CDCl_3$) δ 210 (C=O), 147.2, 146.7, 146.4, 128.2, 128.1, 128.0, 126.9, 126.8, 126.6, 126.1, 126.0, 125.7, 105.8, 89.0, 78.0, 38.6, 38.4, 38.1, 35.1, 30.1, 27.7. Anal. Calcd for $C_{17}H_{18}O_2$: C, 80.28; H, 7.13. Found: C, 80.19; H, 8.00.

Mixture of 5,5-bis(4-chlorophenyl)-2-methyltetrahydrofuran-2-ol and 5,5-bis(4-chlorophenyl)-5-hydroxy-2-pentanone (2b): 42:58 mixture in $CDCl_3$; colorless microcrystals (from petroleum ether/hexane); mp 125−126 °C; IR ($CHCl_3$) ν 3650−3200, 1710; ^{1}H NMR ($CDCl_3$) δ 1.66 (3H, s), 2.30 (3H, s), 1.84−3.40 (8H, m), 7.40 (16H, m). Anal. Calcd for $C_{17}H_{16}O_2Cl_2$: C, 63.17; H, 4.98. Found: C, 63.46; H, 4.86.

Mixture of 5,5-bis(4-fluorophenyl)-2-methyltetrahydrofuran-2-ol and 5,5-bis(4-fluorophenyl)-5-hydroxy-2-pentanone (2c): 41:59 mixture in $CDCl_3$; colorless microcrystals (from petroleum ether/hexane); mp 51.5−52 °C; IR

($CHCl_3$) ν 3650−3200, 1716; ^1H NMR ($CDCl_3$) δ 1.61 (3H, s), 2.11 (3H, s), 2.43−2.83 (8H, m), 6.70−7.56 (16H, m). Anal. Calcd for $C_{17}H_{16}O_2F_2$: C, 70.33; H, 5.55. Found: C, 70.52; H, 5.65.

Mixture of 5,5-bis(4-methylphenyl)-2-methyltetrahydrofuran-2-ol and 5-hydroxy-5,5-bis(4-methylphenyl)-2-pentanone (2d): 42:58 mixture in $CDCl_3$; colorless needles (from petroleum ether/hexane); mp 44−45 °C; IR ($CHCl_3$) ν 3650−3200, 1712; ^1H NMR ($CDCl_3$) δ 1.60 (3H, s), 1.70−3.0 (8H, m), 2.09 (3H, s), 2.29 (12H, s), 7.00−7.40 (16H, m); ^{13}C NMR ($CDCl_3$) δ 210 (C═O), 144.5, 144.0, 143.7, 136.4, 136.2, 139.1, 128.9, 128.8, 128.7, 126.1, 125.9, 125.6, 105.64, 89.0, 77.0, 38.7, 38.4, 38.2, 38.1, 30.1, 27.7, 20.9; MS *m/z* (rel intensity) 282 (M^+, 11), 264 (15), 221 (43), 211 (100), 191 (20), 129 (19), 119 (49), 91 (21), 43 (11). Anal. Calcd for $C_{19}H_{22}O_2$: C, 80.81; H, 7.85; M, 282.1620. Found: C, 80.89; H, 8.00; *m/z* 282.1643.

2(*Z*)-(Carboxymethylene)-5,5-diphenyltetrahydrofuran (3a). An NOE effect was observed between the methylene protons of H-3 and the alkenic proton: colorless needles (from $CHCl_3$/hexane); mp 157.5−158.0 °C; IR ($CHCl_3$) ν 3600−2200, 1680; ^1H NMR ($CDCl_3$) δ 2.73 (2H, t, J = 7.2 Hz), 3.16 (2H, dt, J = 7.2, 1.8 Hz), 5.53 (1H, t, J = 1.8 Hz), 7.1−7.6 (10H, m), 8.2 (1H, bs); ^{13}C NMR ($CDCl_3$) δ 177.4, 143.2, 128.5, 127.7, 125.6, 93.3, 90.3, 36.7, 30.8. Anal. Calcd for $C_{18}H_{16}O_3$: C, 77.12; H, 5.71. Found: C, 77.06; H, 5.75.

2(*Z*)-(Carboxymethylene)-5,5-bis(4-chlorophenyl)tetrahydrofuran (3b): colorless microcrystals (from $CHCl_3$/hexane); mp 167.5−168.0 °C; IR ($CHCl_3$) ν 3600−2400, 1685; ^1H NMR ($CDCl_3$) δ 2.75 (2H, t, J = 7.2 Hz), 3.25 (2H, dt, J = 7.2, 1.8 Hz), 5.65 (1H, t, J = 1.6 Hz), 7.43 (8H, m), 8.5 (1H, bs). Anal. Calcd for $C_{18}H_{14}O_3Cl_2$: C, 61.91; H, 4.04. Found: C, 61.87; H, 4.02.

2(*Z*)-(Carboxymethylene)-5,5-bis(4-florophenyl)tetrahydrofuran (3c): colorless microcrystals (from CH_2Cl_2); mp 149−150 °C; IR ($CHCl_3$) ν 3600−2200, 1680; ^1H NMR ($CDCl_3$) δ 2.80 (2H, t, J = 7.2 Hz), 3.20 (2H, dt, J = 7.2 and 1.8 Hz), 5.75 (1H, t, J = 1.6 Hz), 6.90−7.60 (8H, m), 9.6 (1H, bs). Anal. Calcd for $C_{18}H_{14}O_3F_2$: C, 68.35; H, 4.46. Found: C, 67.97; H, 4.54.

2(*Z*)-(Carboxymethylene)-5,5-bis(4-methylphenyl)tetrahydrofuran (3d): colorless needles (petroleum ether/hexane); mp 127.5−128.5 °C; IR ($CHCl_3$) ν 3600−2200, 1680; ^1H NMR ($CDCl_3$) δ 2.29 (6H, s), 2.67 (2H, t, J = 7.2 Hz), 3.14 (2H, dt, J = 7.2, 1.8 Hz), 5.49 (1H, t, J = 1.8 Hz), 6.9−7.5 (8H, m), 8.8 (1H, bs); ^{13}C NMR ($CDCl_3$) δ 177.6, 140.5, 137.4, 129.1, 125.6, 93.4, 90.1, 36.7, 31.0, 21.0. Anal. Calcd for $C_{20}H_{20}O_3$: C, 77.89; H, 6.54. Found: C, 77.80; H, 6.61.

5,5-Bis(4-chlorophenyl)-4-penten-2-one (4b): colorless needles (from $CHCl_3$/hexane); mp 107−108 °C; IR ($CHCl_3$) ν 1715; ^1H NMR ($CDCl_3$) δ 2.11 (3H, s), 3.25 (2H, d, J = 7.8 Hz), 6.30 (1H, t, J = 7.8 Hz), 7.00−7.50 (8H, m). Anal. Calcd for $C_{17}H_{14}OCl_2$: C, 66.90; H, 4.62. Found: C, 66.73; H, 4.66.

Oxidation of a Mixture of 1,1-Diarylethenes and Diketene in the Presence of Alcohols. A mixture of alkene **1** (1 mmol), alcohol (200 mmol), and glacial acetic acid (10 mL) in a 50 mL flask was placed in an appropriate temperature oil bath and stirred. Diketene (4 mmol) was added, immediately followed by addition of manganese(III) acetate (1.5−4 mmol). The flask was fitted with a reflux condenser and a gas inlet tube connected with argon, and the reaction was allowed to proceed until the reaction mixture turned colorless or yellow. The workup and separation were done using the procedure previously mentioned. The result of the reactions at the molar ratio of ethene:diketene:manganese(III) acetate dihydrate:alcohol = 1:4:4:200 are summarized in Table 2. Specfic details are given below.

5,5-Bis(4-chlorophenyl)-2-ethoxy-2-methyltetrahydrofuran (5b, R = Et): colorless microcrystals (from petroleum ether/hexane); mp 57−58 °C; ^1H NMR ($CDCl_3$) δ 0.85 (3H, t, J = 7 Hz), 1.56 (3H, s), 1.7−2.9 (4H, m), 3.70 (2H, q, J = 7 Hz), 7.3−7.8 (8H, m). Anal. Calcd for $C_{19}H_{20}O_2Cl_2$: C, 64.96; H, 5.73. Found: C, 65.07; H, 5.83.

2-[(Ethoxycarbonyl)methyl]-2-ethoxy-5,5-bis(4-methylphenyl)tetrahydrofuran (6d, R = Et): colorless liquid; IR ($CHCl_3$) ν 1735; ^1H NMR ($CDCl_3$) δ 0.91 (3H, t, J = 7 Hz), 1.21 (3H, t, J = 7.1 Hz), 2.0−2.9 (4H, m), 2.28 (6H, s), 2.63 (1H, d, J = 13.7 Hz), 3.19 (1H, d, J = 13.7 Hz), 3.58 (2H, q, J = 7 Hz), 4.13 (2H, q, J = 7.1 Hz), 7.1−7.3 (8H, m); ^{13}C NMR ($CDCl_3$) δ 169.6, 144.2, 143.8, 136.1, 128.7, 128.6, 128.6, 126.6, 15.9, 125.4, 107.1, 89.3, 60.4, 56.9, 42.2, 37.8, 37.2, 21.0, 20.9, 15.1, 14.1; MS *m/z* (rel intensity) 382 (M^+, 29), 337 (65), 320 (25), 291 (42), 245 (100), 221 (77), 211 (55), 182 (35), 172 (82), 143 (59), 129 (43), 119 (69), 105 (22), 91 (34), 43 (23); HRMS found *m/z* 382.2095, calcd for $C_{24}H_{30}O_4$ M, 382.2144.

2-[(Ethoxycarbonyl)methylene]-5,5-bis(4-methylphenyl)tetrahydrofuran (7d, R = Et): yellowish oil; IR ($CHCl_3$) ν 1696, 1642; ^1H NMR ($CDCl_3$) δ 1.24 (3H, t, J = 7.2 Hz), 2.29 (6H, s), 2.67 (2H, t, J = 7.2 Hz), 3.13 (2H, dt, J = 7.2, 1.8 Hz), 4.12 (2H, q, J = 7.2 Hz), 5.50 (1H, t, J = 1.8 Hz), 7.0−7.3 (8H, m); ^{13}C NMR ($CDCl_3$) δ 175.3, 168.5, 140.6, 137.2, 129.0, 125.6, 92.7, 90.4, 59.2, 36.8, 30.5, 20.9, 14.4; MS *m/z* (rel intensity) 336 (M^+, 52), 290 (30), 264 (20), 248 (14), 222 (50), 221 (100), 207 (22), 191 (14), 129 (46), 115 (32), 105 (19), 83 (38); HRMS found *m/z* 336.1713, calcd for $C_{22}H_{24}O_3$ M, 336.1725.

Manganese(III) Oxidation of a Mixture of 1,1-Diarylthenes 1a−e and Diketene in the Presence of Amines. A solution of 1,1-diarylethene **1** (1 mmol) and an amine (3−12 mmol) in a solvent (15 mL) was heated in an oil bath. Diketene (3−24 mmol) and then manganese(III) acetate dihydrate (3−4 mmol) were added, and the mixture was heated under reflux until the dark-brown color of Mn(III) acetate disappeared. After the solvent was removed *in vacuo*, the residue was triturated with water (30 mL), and then the aqueous solution was extracted with chloroform three times (30, 20, and 20 mL, respectively). The extract was dried with anhydrous sodium sulfate and concentrated to dryness. The products were separated by silica gel TLC (Wakogel B-10) with diethyl ether/hexane (8:2 v/v) or methanol/dichloromethane (2:23 v/v) as the developing solvent. Analytical samples were further purified by recrystallization from the solvent specified in the parentheses except for liquid products. The molar ratios, reaction times, and product yields are summarized in Tables 3 and 4. Specific details are given below.

3-Acetyl-2-(butylamino)-5,5-diphenyl-4,5-dihydrofuran (9a, R = Bu): colorless microcrystals (from $CHCl_3$/hexane); mp 94 °C; IR ($CHCl_3$) ν 3500, 1650; ^1H NMR ($CDCl_3$) δ 0.91 (3H, t, J = 6.44 Hz),1.2−1.7 (4H, m), 1.99 (3H, s), 3.44 (2H, t, J = 7.76 Hz), 3.64 (2H, s), 7.33 (10H, m), 9.0 (1H, br); ^{13}C NMR ($CDCl_3$) δ 188.7, 166.6, 144.3, 128.3, 127.7, 125.7, 93.0, 86.0, 42.8, 41.3, 32.3, 19.8, 26.8, 13.6. Anal. Calcd for $C_{25}H_{25}O_2N$: C, 78.77; H, 7.51; N, 4.17. Found: C, 79.02; H, 6.67; N, 4.29.

3-Acetyl-2-(*tert*-butylamino)-5,5-diphenyl-4,5-dihydrofuran (9a, R = *t*-Bu): colorless microcrystals (from $CHCl_3$/hexane); mp 139.5−140 °C; IR ($CHCl_3$) ν 3500, 1633; ^1H NMR ($CDCl_3$) δ 1.43 (9H, s), 2.00 (3H, s), 3.58 (2H, s), 7.33 (10H, m), 9.5 (1H, br); ^{13}C NMR ($CDCl_3$) δ 188.2, 166.3, 144.4, 128.3, 127.7, 125.7, 92.9, 86.8, 52.1, 41.8, 30.1, 26.8. Anal. Calcd for $C_{22}H_{25}O_2N$: C, 78.77; H, 7.51; N, 4.17. Found: C, 78.85; H, 7.68; N, 4.22.

3-Acetyl-2-(benzylamino)-5,5-diphenyl-4,5-dihydrofuran (9a, R = Bn): colorless plates (from $CHCl_3$/hexane); mp 158 °C; IR ($CHCl_3$) ν 3550, 1649; ^1H NMR ($CDCl_3$) δ 2.0 (3H, s), 3.65 (2H, s), 4.58 (2H, s), 7.26 (15H, m), 9.32 (1H, br); ^{13}C NMR ($CDCl_3$) δ 189.5, 166.2, 144.9, 138.0, 128.7, 128.3, 127.7, 127.4, 127.3, 125.7, 93.3, 86.4, 45.5, 43.0, 27.0. Anal. Calcd for $C_{25}H_{23}O_2N$: C, 81.27; H, 6.27; N, 3.79. Found: C, 81.32; H, 6.36; N, 3.74.

3-Acetyl-2-(*tert*-butylamino)-5,5-bis(4-fluorophenyl)-4,5-dihydrofuran (9c, R = *t*-Bu): colorless needles (from $CHCl_3$/hexane); mp 109 °C; IR ($CHCl_3$) ν 3460, 1642; ^1H NMR ($CDCl_3$) δ 1.42 (9H, s), 2.01 (3H, s), 3.55 (2H, s), 6.9−7.5 (8H, m), 9.45 (1H, br); ^{13}C NMR ($CDCl_3$) δ 188.5, 167.8, 156.8, 166.1, 140.1, 140.0, 127.9, 127.5, 115.8, 114.9, 93.0, 86.6, 52.3, 42.0, 30.1, 26.9. Anal. Calcd for $C_{22}H_{23}O_2NF_2$: C, 71.14; H, 6.24; N, 3.77. Found: C, 71.08; H, 6.35; N, 3.72.

3-(Butylcarbamoyl)-2-hydroxy-2-methyl-5,5-diphenyltetrahydrofuran (10a, R = Bu): colorless needls (from $CHCl_3$/hexane); mp 141−142 °C; IR ($CHCl_3$) ν 3500−3200, 1655; ^{1}H NMR (CDCl$_3$) δ 0.91 (3H, t, J = 6.44 Hz), 1.2−1.7 (4H, m), 1.6 (3H, s), 2.5−2.8 (1H, dd, J_a = 8.2 Hz, J_b = 14 Hz), 2.9 (2H, bt, J = 7.7 Hz), 3.0−3.3 (2H, dd, J_a = 8.2 Hz, J_b = 14 Hz), 4.9 (1H, s), 6.5 (1H, br), 7.0−7.6 (10H, m); ^{13}C NMR (CDCl$_3$) δ 171.1, 146.7, 145.8, 128.1, 128.0, 126.8, 126.0, 125.8, 125.6, 103.7, 87.1, 53.0, 43.0, 41.3, 39.2, 19.9, 26.8, 13.6. Anal. Calcd for $C_{22}H_{27}O_3N$: C, 74.76; H, 7.70; N, 3.96. Found: C, 74.57; H, 7.53; N, 3.85.

3-(*tert*-Butylcarbamoyl)-2-hydroxy-2-methyl-5,5-diphenyltetrahydrofuran (10a, R = *t*-Bu): colorless microcrystals (from CHCl$_3$/hexane); mp 178 °C; IR (CHCl$_3$) ν 3500−3200, 1658; ^{1}H NMR (CDCl$_3$) δ 1.36 (9H, s), 1.65 (3H, s), 2.45−2.7 (1H, dd, J_a = 8 Hz, J_b = 14 Hz), 2.75−3.1 (2H, dd, J_a = 8 Hz, J_b = 14 Hz), 4.85 (1H, br), 5.8 (1H, br), 7.0−7.6 (10H, m); ^{13}C NMR (CDCl$_3$) δ 170.7, 146.7, 146.0, 128.2, 128.1, 126.9, 126.1, 125.8, 125.7, 103.8, 87.1, 53.6, 51.7, 43.1, 26.7, 27.0. Anal. Calcd for $C_{22}H_{27}O_3N$: C, 74.76; H, 7.70; N, 3.96. Found: C, 74.47; H, 7.67; N, 4.05.

3-(Benzylcarbamoyl)-2-hydroxy-2-methyl-5,5-diphenyltetrahydrofuran (10a, R = Bn): colorless microcrystals (from CHCl$_3$/hexane); mp 117 °C; IR (CHCl$_3$) ν 3500−3200, 1657; ^{1}H NMR (CDCl$_3$) δ 1.65 (3H, s), 2.5−2.8 (1H, dd, J_a = 8.2 Hz, J_b = 14 Hz), 2.9−3.2 (2H, dd, J_a = 8.2 Hz, J_b = 14 Hz Hz), 4.37 (1H, s), 4.4 (2H, d, J = 5.6 Hz), 6.6 (1H, br), 7.0−7.6 (15H, m); ^{13}C NMR (CDCl$_3$) δ 170.8, 146.6, 145.7, 137.7, 128.7, 128.7, 128.1, 127.6, 127.0, 126.0, 125.6, 103.8, 87.3, 53.4, 43.9, 43.6, 26.9. Anal. Calcd for $C_{25}H_{25}O_3N$: C, 77.49; H, 6.50; N, 3.61. Found: C, 77.12; H, 6.64; N, 3.66.

3-(*tert*-Butylcarbamoyl)-5,5-bis(4-chlorophenyl)-2-hydroxy-2-methyltetrahydrofuran (10b, R = *t*-Bu): colorless microcrystals (from CHCl$_3$/hexane); mp 195 °C; IR (CHCl$_3$) ν 3440, 3375, 1655; ^{1}H NMR (CDCl$_3$) δ 1.33 (9H, s), 1.62 (3H, s), 2.4−3.2 (3H, m), 5.08 (1H, s), 5.8 (1H, br), 7.1−7.5 (8H, m); ^{13}C NMR (CDCl$_3$) δ 170.5, 145.0, 144.2, 133.1, 128.4, 128.3, 127.5, 127.1, 104.0, 86.2, 53.5, 51.9, 43.1, 28.7, 26.9. Anal. Calcd for $C_{22}H_{25}O_3NCl_2$: C, 62.56; H, 5.97; N, 3.32. Found: C, 62.33; H, 6.02; N, 3.34.

3-(*tert*-Butylcarbamoyl)-5,5-bis(4-fluorophenyl)-2-hydroxy-2-methyltetrahydrofuran (10c, R=*t*-Bu): colorless microcrystals (from CHCl$_3$/hexane); mp 141−142 °C; IR (CHCl$_3$) ν 3444, 3388, 1658; ^{1}H NMR (CDCl$_3$) δ 1.31 (9H, s), 1.59 (3H, s), 2.4−3.1 (3H, m), 5.5 (1H, s), 5.94 (1H, br), 6.8−7.5 (8H, m); ^{13}C NMR (CDCl$_3$) δ 170.6, 167.3, 156.3, 141.7, 141.6, 128.0, 127.7, 127.6, 127.2, 115.5, 115.4, 114.6, 114.4, 104.0, 86.3, 53.5, 51.9, 43.4, 28.7, 26.93. Anal. Calcd for $C_{22}H_{25}O_3NF_2$: C, 67.85; H, 6.47; N, 3.60. Found: C, 67.96; H, 6.58; N, 3.43.

3-(*tert*-Butylcarbamoyl)-2-hydroxy-5,5-bis(4-methylphenyl)-2-methyltetrahydrofuran (10d, R = *t*-Bu): colorless microcrystals (from CHCl$_3$/hexane); mp 144−145 °C; IR (CHCl$_3$) ν 3440, 3400, 1657; ^{1}H NMR (CDCl$_3$) δ 1.32 (9H, s), 1.62 (3H, s), 2.27 (3H, s), 2.30 (3H, s), 2.4−3.2 (3H, m), 4.81 (1H, s), 5.88 (1H, br), 6.95−7.5 (8H, m); ^{13}C NMR (CDCl$_3$) δ 170.8, 144.0, 144.3, 136.4, 136.4, 128.81, 128.77, 126.0, 125.6, 103.7, 87.0, 53.6, 51.7, 43.1, 28.7, 26.9, 20.94. Anal. Calcd for $C_{24}H_{31}O_3N$: C, 75.56; H, 8.19; N, 3.67. Found: C, 75.85; H, 7.98; N, 3.79.

3-(*tert*-Butylcarbamoyl)-2-hydroxy-5,5-bis(4-methoxyphenyl)-2-methyltetrahydrofuran (10e, R = *t*-Bu): colorless microcrystals (from CHCl$_3$/hexane); mp 147 °C; IR (CHCl$_3$) ν 3448, 3380, 1658; ^{1}H NMR (CDCl$_3$) δ 1.31 (9H, s), 1.59 (3H, s), 2.4−3.0 (3H, m), 3.71 (3H, s), 3.75 (3H, s), 5.28 (1H, s), 6.28 (1H, br), 6.76 (2H, m), 6.81 (2H, m), 7.29 (2H, m), 7.30 (2H, m); ^{13}C NMR (CDCl$_3$) δ 170.9, 158.4, 158.4, 139.3, 138.3, 127.5, 126.9, 113.4, 113.4, 103.6, 86.7, 55.2, 53.7, 51.6, 43.3, 28.7, 27.0. Anal. Calcd for $C_{24}H_{31}O_5N$: C, 69.71; H, 7.55; N, 3.39. Found: C, 69.94; H, 7.40; N, 3.43.

3-(Butylcarbamoyl)-2-methyl-5,5-diphenyl-4,5-dihydrofuran (11a, R = Bu): colorless needles (from CHCl$_3$/hexane); mp 148 °C; IR (CHCl$_3$) ν 3472, 1669; ^{1}H NMR (CDCl$_3$) δ 0.91 (3H, t, J = 6.44 Hz),1.2−1.7 (4H, m), 2.38 (3H, t, J = 1.61 Hz), 3.23 (2H, bt, J = 7.7 Hz), 3.56 (2H, q, J = 1.61 Hz), 5.16 (1H, br), 7.23−7.5 (10H, m). Anal. Calcd for $C_{22}H_{25}O_2N$: C, 78.77; H, 7.51; N, 4.17. Found: C, 78.71; H, 7.45; N, 4.30.

3-(*tert*-Butylcarbamoyl)-2-methyl-5,5-diphenyl-4,5-dihydrofuran (11a, R = *t*-Bu): colorless needles (from CHCl$_3$/hexane); mp 208 °C; IR (CHCl$_3$) ν 3456, 1668; ^{1}H NMR (CDCl$_3$) δ 1.36 (9H, s), 2.36 (3H, t, J = 1.61 Hz), 3.47 (2H, q, J = 1.61 Hz), 4.95 (1H, br), 7.25−7.41 (10H, m); ^{13}C NMR (CDCl$_3$) δ 165.2, 162.6, 144.3, 128.3, 127.5, 125.7, 103.4, 90.1, 51.1, 45.2, 29.1, 13.9. Anal. Calcd for $C_{22}H_{25}O_2N$: C, 78.77; H, 7.51; N, 4.17. Found: C, 78.98; H, 7.39; N, 4.23.

3-(Benzylcarbamoyl)-2-methyl-5,5-diphenyl-4,5-dihydrofuran (11a, R = Bn): colorless microcrystals (from CHCl$_3$/hexane); mp 187 °C; IR (CHCl$_3$) ν 3464, 1668; ^{1}H NMR (CDCl$_3$) δ 2.41 (3H, t, J = 1.7 Hz), 3.51 (2H, q, J = 1.7 Hz), 4.46 (2H, d, J = 5.71 Hz), 5.55 (1H, br), 7.0−7.6 (15H, m); ^{13}C NMR (CDCl$_3$) δ 165.3, 164.0, 145.2, 138.7, 128.7, 128.4, 127.9, 127.7, 127.6, 127.5, 102.4, 90.7, 42.6, 43.4, 14.1. Anal. Calcd for $C_{25}H_{23}O_2N$: C, 81.27; H, 6.27; N, 3.79. Found: C, 81.53; H, 6.39; N, 3.91.

3-(*tert*-Butylcarbamoyl)-5,5-bis(4-chlorophenyl)-2-methyl-4,5-dihydrofuran (11b, R = *t*-Bu): colorless needles (from CHCl$_3$/hexane); mp 229−230 °C; IR (CHCl$_3$) ν 3460, 1670; ^{1}H NMR (CDCl$_3$) δ 1.31 (9H, s), 2.34 (3H, t, J = 1.7 Hz), 3.42 (2H, q, J = 1.7 Hz), 4.94 (1H, br), 7.29 (8H, m); ^{13}C NMR (CDCl$_3$) δ 164.8, 162.2, 143.4, 133.8, 128.7, 127.1, 103.6 (C-3), 89.2, 51.3, 45.1, 29.1, 13.9. Anal. Calcd for $C_{22}H_{23}O_2NCl_2$: C, 65.35; H, 5.73; N, 3.46. Found: C, 65.14; H, 5.84; N, 3.32.

3-(*tert*-Butylcarbamoyl)-5,5-bis(4-fluorophenyl)-2-methyl-4,5-dihydrofuran (11c, R = *t*-Bu): colorless microcrystals (from CHCl$_3$/hexane); mp 191 °C; IR (CHCl$_3$) ν 3460, 1670; ^{1}H NMR (CDCl$_3$) δ 1.37 (9H, s), 2.34 (3H, t, J = 1.76 Hz), 3.42 (2H, q, J = 1.76 Hz), 4.92 (1H, br), 6.9−7.45 (8H, m); ^{13}C NMR (CDCl$_3$) δ 164.9, 162.3, 167.6, 156.7, 141.0, 140.9, 127.7, 127.4, 115.8, 114.8, 103.5, 89.3, 51.2, 45.4, 29.1, 13.6. Anal. Calcd for $C_{22}H_{23}O_2NF_2$: C, 71.14; H, 6.24; N, 3.77. Found: C, 71.26; H, 6.28; N, 3.70.

3-(*tert*-Butylcarbamoyl)-5,5-bis(4-methylphenyl)-2-methyl-4,5-dihydrofuran (11d, R = *t*-Bu): colorless needles (from CHCl$_3$/hexane); mp 213 °C; IR (CHCl$_3$) ν 3460, 1667; ^{1}H NMR (CDCl$_3$) δ 1.36 (9H, s), 2.32 (6H, s), 2.36 (3H, t, J = 1.76 Hz), 3.45 (2H, q, J = 1.76 Hz), 4.92 (1H, br), 7.1 (4H, m), 7.25 (4H, m); ^{13}C NMR (CDCl$_3$) δ 165.3, 162.7, 142.6, 137.2, 129.0, 125.7, 103.2, 90.1, 51.1, 45.3, 29.2, 21.0, 14.0. Anal. Calcd for $C_{24}H_{29}O_2N$: C, 79.30; H, 8.04; N, 3.85. Found: C, 79.09; H, 8.19; N, 3.83.

3-(*tert*-Butylcarbamoyl)-5,5-bis(4-methoxyphenyl)-2-methyl-4,5-dihydrofuran (11e, R = *t*-Bu): colorless microcrystals (from CHCl$_3$/hexane); mp 177−178 °C; IR (CHCl$_3$) ν 3460, 1667; ^{1}H NMR (CDCl$_3$) δ 1.36 (9H, s), 2.34 (3H, t, J = 2.2 Hz), 3.41 (2H, q, J = 2.2 Hz), 3.78 (6H, s), 4.95 (1H, br), 6.85 (4H, m), 7.24 (4H, m); ^{13}C NMR (CDCl$_3$) δ 165.3, 162.6, 158.9, 137.7, 127.1, 113.6, 103.2, 89.9, 55.3, 51.1, 45.4, 29.1, 14.0. Anal. Calcd for $C_{24}H_{29}O_4N$: C, 72.89; H, 7.39; N, 3.54. Found: C, 72.79; H, 7.51; N, 3.67.

3-[(2-Hydroxyethyl)carbamoyl]-2-methyl-5,5-diphenyl-4,5-dihydrofuran (12a): colorless needles (from CHCl$_3$/hexane); mp 151.5 °C; IR (CHCl$_3$) ν 3472−3200, 1666; ^{1}H NMR (CDCl$_3$) δ 2.38 (3H, t, J = 1.62 Hz), 3.44 (2H, t, J = 5.13 Hz), 3.52 (2H, q, J = 1.62 Hz), 3.69 (2H, t, J = 5.13 Hz), 5.82 (1H, br t), 7.25−7.40 (10H, m); ^{13}C NMR (CDCl$_3$) δ 166.6, 164.3, 145.0, 128.4, 127.6, 125.7, 102.2, 90.8, 62.8, 44.5, 42.4, 14.1. Anal. Calcd for $C_{20}H_{21}O_3N$: C, 74.28; H, 6.54; N, 4.33. Found: C, 74.36; H, 6.61; N, 4.39.

2-Methyl-3-[[2-[(3-oxobutanoyl)oxy]ethyl]carbamoyl]-5,5-diphenyl-4,5-dihydrofuran (13a, X = O, *n* = 2): colorless microcrystals (from CHCl$_3$/hexane); mp 96 °C; IR (CHCl$_3$) ν 3450, 1745, 1717, 1667; ^{1}H NMR (CDCl$_3$) δ 2.20 (3H, s), 2.38 (3H, t, J = 1.62 Hz), 3.5 (2H, s), 3.52 (2H, t, J = 5.13 Hz), 3.56 (2H, q, J = 1.62 Hz), 4.25 (2H, t, J = 5.13 Hz), 5.85 (1H, br), 7.16−7.60 (10H, m); ^{13}C NMR (CDCl$_3$) δ 201.1, 166.9, 165.6, 163.8, 145.3, 128.3, 127.5, 125.7, 102.6, 90.8, 64.3, 50.0, 44.2, 38.1, 30.3, 14.0. Anal. Calcd for $C_{24}H_{25}O_5N$: C, 70.74; H, 6.18; N, 3.44. Found: C, 70.71; H, 6.41; N, 3.35.

2-Methyl-3-[[3-(3-oxobutanamido)propyl]carbamoyl]-5,5-diphenyl-4,5-dihydrofuran (13a, X = NH, *n* = 3): colorless microcrystals (from CHCl$_3$/hexane); mp 134−135 °C; IR (CHCl$_3$) ν 3470, 3344, 1711, 1663, 1616; ^{1}H NMR (CDCl$_3$) δ 1.6 (2H, m), 2.23 (3H, s), 2.38 (3H, t, J = 2.2 Hz), 3.1−3.4 (4H, m), 3.38 (2H, s), 3.57 (2H, q, J = 2.2 Hz), 6.16 (1H, br), 7.1−7.6 (10H, m); ^{13}C NMR (CDCl$_3$) δ 204.0, 166.5, 166.0, 163.4, 145.2, 128.4, 127.5, 125.8, 102.8, 90.7, 50.1, 44.4, 36.2, 35.4, 30.9, 29.7, 14.0. Anal. Calcd for $C_{25}H_{28}O_4N_2$: C, 71.41; H, 6.71; N, 6.66. Found: C, 71.05; H, 6.54; N, 6.54.

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Supporting Information Available: IR, ^{1}H NMR, ^{13}C NMR, and MS spectral data and melting points for compounds **3e**, **4a**,**c**−**e**, **5a**,**c**,**d**, **6a**−**c**, **7a**−**c**, **8a**, **9b**, **9c** (R = *t*-Bu), **14a**, **15a**, and **16a** (10 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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