JOC*Note*

Transformation of Fused Bicyclic and Tricyclic β-Lactones to Fused γ-Lactones and 3(2*H*)-Furanones via Ring Expansions and O−H Insertions

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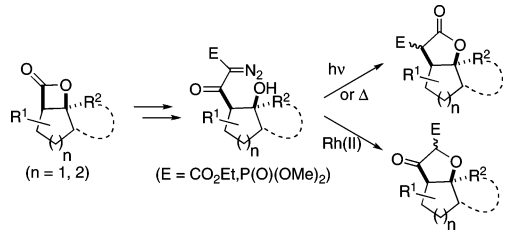

A two-step strategy for conversion of β-lactones to γ-lactones and 3(2*H*)-furanones was developed involving initial acyl C−O cleavage leading to δ-hydroxy-α-diazo-β-ketoesters and β-ketophosphonates. Subsequent tandem Wolff rearrangement/lactonization of these α-diazo intermediates provided *cis*-fused γ-lactones efficiently under photolytic or thermolytic conditions. In addition, *cis*-fused 3(2*H*)-furanones were obtained by rhodium(II)-catalyzed O−H insertion reactions of the δ-hydroxy-α-diazo intermediates.

Several methods for the asymmetric synthesis of β-lactones have appeared recently[1] and have stimulated the development of new transformations of these versatile intermediates.[2] As part of our ongoing efforts to further exploit β-lactones as synthetic intermediates, we have studied various transformations involving both acyl C−O[3] or alkyl C−O[4] cleavage with diverse nucleophiles. In addition, we previously reported a catalytic, asymmetric, intramolecular nucleophile catalyzed aldol-lactonization (NCAL) process of aldehyde acids that enables access to optically active bicyclic-β-lactones employing quinidine and quinine as nucleophilic catalysts (Figure 1 (i)).[5] More recently, we expanded this process to keto acid substrates employing 4-pyrrolidinopyridine (4-PPY) as a nucleophilic promoter allowing access to a variety of functionalized bicyclic and tricyclic carbocycle-fused β-lactones[6] and heterocycle fused-β-lactones[7] with good to excellent diastereoselectivity based on substrate control (Figure 1 (ii)).

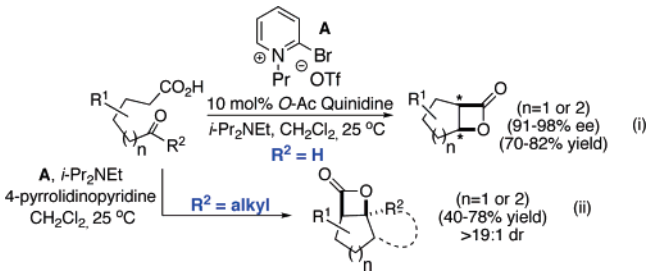

FIGURE 1. Intramolecular cyclizations leading to bicyclic and tricyclic β-lactones.

The frequent occurrence of carbocycle-fused γ-lactones and both 3(2*H*)-furanones and derivable 3-hydroxy tetrahydrofurans in natural products[8] led us to consider expedient strategies for conversion of bicyclic and tricyclic β-lactones to these moieties. While several elegant strategies have been developed for the synthesis of these systems,[9,10] the combination of the catalytic, asymmetric NCAL process of aldehyde acids or bis-cyclization of keto acids in conjunction with an efficient method for conversion of β-lactones to γ-lactones and 3(2*H*)-furanones appeared to provide a particularly expedient strategy. Building on previous work of Moody,[11] we envisioned that β-lactone acyl C−O cleavage with ethyl lithio-α-diazo acetate would provide

(1) For a review, see: (a) Yang, H. W.; Romo, D. *Tetrahedron* **1999**, *55*, 6403. For more recent examples, see: (b) Evans, D. A.; Janey, J. M. *Org. Lett*. **2001**, *3*, 2125. (c) Cortez, G. S.; Tennyson, R. L.; Romo, D. *J. Am. Chem. Soc*. **2001**, *123*, 7945. (d) Nelson, S. G.; Zhu, C.; Shen, X. *J. Am. Chem. Soc*. **2004**, *126*, 14. (e) Zhu, C.; Shen, X.; Nelson, S. G. *J. Am. Chem. Soc*. **2004**, *126*, 5352. (f) Calter, M. A.; Tretyak, O. A.; Flascheriem. C. *Org. Lett*. **2005**, *7*, 1809. (g) Wilson, J. E.; Fu, G. C. *Angew. Chem., Int. Ed*. **2004**, *43*, 6358. (h) Gnanadesikan, V.; Corey, E. J. *Org. Lett*. **2006**, *8*, 4943. (i) Lin, Y.; Boucau, J.; Li, Z.; Casarotto, V.; Lin, J.; Nguyen, A. N.; Ehrmantraut, J. *Org. Lett*. **2007**, *9*, 567.

(2) For a review, see: (a) Pommier, A.; Pons, J.-M. *Synthesis* **1995**, 729. (b) Wang, Y.; Tennyson, R.; Romo, D. *Heterocycles* **2004**, *64*, 605. See also ref 1a. For selected recent examples, see: (c) Donohoe, T. J.; Sintim, H. O.; Sisangia, L.; Harling, J. D. *Angew. Chem., Int. Ed.* **2004**, *43*, 2293. (d) Getzle, Y. D. Y. L.; Kundnani, V.; Lobkovsky, E. B.; Coates, G. W. *J. Am. Chem. Soc.* **2004**, *126*, 6842. (e) Mitchell, T. A.; Romo, D. *Heterocycles* **2005**, *66*, 627. (f) Shen, X.; Wasmuth, A. S.; Zhao, J.; Zhu, C.; Nelson, S. G. *J. Am. Chem. Soc.* **2006**, *128*, 7438. (g) Reddy, L. R.; Corey, E. J. *Org. Lett*. **2006**, *8*, 1717.

(3) Yang, H. W.; Romo, D. *J. Org. Chem.* **1999**, *64*, 7657.

(4) (a) Zhao, C.; Romo, D. *Tetrahedron Lett.* **1997**, *38*, 6537. (b) Yokota, Y.; Cortez, G. S.; Romo, D. *Tetrahedron* **2002**, *58*, 7075. (c) Zhang, W.; Matla, A.; Romo, D. *Org. Lett*. **2007**, *9*, 2111.

(5) (a) Cortez, G. S.; Oh, S. H.; Romo, D. *Synthesis* **2001**, 1731. (b) Oh, S. H.; Cortez, G. S.; Romo, D. *J. Org. Chem*. **2005**, *70*, 2835.

(6) Riyad, H.; Lee, C. S.; Purohit, V.; Romo, D. *Org. Lett.* **2006**, *8*, 4363.

(7) Ma, G.; Nguyen, H.; Romo, D. *Org. Lett*. **2007**, *9*, 2143.

(8) Selected examples: (a) Schmidt, T. J. *Current Org. Chem*. **1999**, *3*, 577. (b) Saku, F.; Ohkuma, H.; Koshiyama, H.; Naito, T.; Kawaguchi, H. *Chem. Pharm. Bull.* **1976**, *24*, 114. (c) Hata, K.; Kozowa, M.; Baba, K.; Knonoshima, M.; Chi, H. J. *Tetrahedron Lett.* **1970**, *11*, 4379.

(9) For lead references to synthesis of *cis*-fused bicyclic γ-lactones, see: (a) Corey, E. J.; Gross, A. W. *Tetrahedron Lett.* **1985**, *26*, 4291. (b) Junji, I. *Trends in Org. Chem*. **1990**, *1*, 23. (c) Lee, G. H.; Choi, E. B.; Lee, E.; Pak, C. S. *J. Org. Chem*. **1994**, *59*, 1428. (d) Paquette, L. A.; Sturino, C. F.; Wang, X.; Prodger, J. C.; Koh, D. *J. Am. Chem. Soc*. **1996**, *118*, 5620. (e) Black, H. T.; Smith, D. C.; Eisenbeis, S. A.; Peterson, K. A.; Harmon, M. S. *Chem. Commun*. **2001**, 753. (f) Yu, M.; Pagenkopf, B. L. *Org. Lett*. **2003**, *5*, 4639. (g) Dams, I.; Bialonska, A.; Ciunik, Z.; Wawrzenczyk, C. *Tetrahedron: Asymmetry* **2005**, *16*, 2087.

(10) For lead references to the synthesis of *cis*-fused 3(2*H*)-furanones, see: (a) Smith, A. B., III; Empfield, J. R.; Vaccaro, H. A. *Tetrahedron Lett*. **1989**, *30*, 7325. (b) Linderman, R. J.; Viviani, F. G.; Kwochka, W. R. *Tetrahedron Lett.* **1992**, *33*, 3571. (c) Cossy, J.; Bellosta, V.; Ranaivosata, J.; Gille, B. *Tetrahedron* **2001**, *57*, 5173. (d) Sha, C.; Huang, S.; Zhan, Z. *J. Org. Chem.* **2002**, *67*, 831. (e) Kuroda, H.; Tomita, I.; Endo, T. *Org. Lett*. **2003**, *5*, 129. (f) Muthusamy, S.; Gnanaprakasam, B.; Suresh, E. *Org. Lett*. **2005**, *7*, 4577.

(11) (a) Moody, C. J.; Taylor, R. J. *Tetrahedron Lett.* **1987**, *28*, 5351. (b) Moody, C. J.; Taylor, R. J. *J. Chem. Soc., Perkin Trans. 1* **1989**, 721. (c) Davies, M. J.; Moody, C. J.; Taylor, R. J. *J. Chem., Soc. Perkin Trans. 1* **1991**, 1. (d) Davies, M. J.; Moody, C. J. *J. Chem. Soc., Perkin Trans. 1* **1991**, 9.

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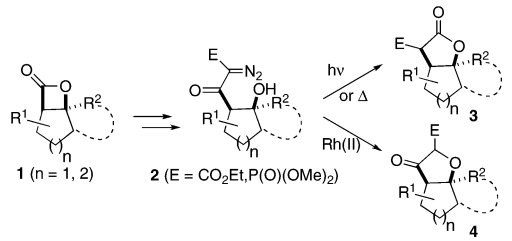
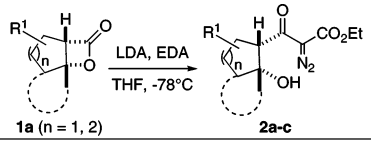


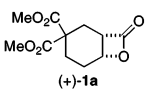
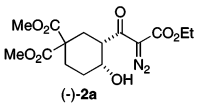
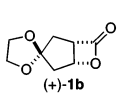
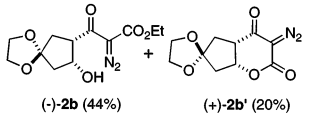
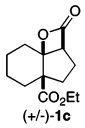
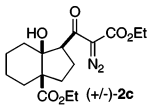
FIGURE 2. General strategy for conversion of bi-/tricyclic β-lactones to bi-/tricyclic γ-lactones and 3(2*H*)-furanones.

versatile α-diazo intermediates[12] **2** which could undergo a tandem Wolff rearrangement/lactonization[13] to generate *cis*-carbocycle-fused γ-lactones **3** (Figure 2). Alternatively, an O−H insertion would furnish *cis*-carbocycle-fused 3(2*H*)-furanones **4** utilizing the rhodium(II)-catalyzed process originally developed by Teyssié,[14] subsequently demonstrated in an intramolecular setting by Rapoport[15] and further developed by Moody, Padwa, Calter, and others for 3(2*H*)-furanone synthesis.[16] Previous studies of lactone cleavage reactions with lithiated diazo carbonyl compounds have been limited to five- to eight-membered lactones.[17] Building on these previous studies, we recognized that α-dimethyl phosphonate γ-lactones **3** and α-dimethyl phosphonate 3(2*H*)-furanones **4** would be accessible from α-diazo phosphonates **2** (E = P(O)(OMe)$_2$) if β-lactones **1** could be transformed to diazo compounds **2**.[11c] The implementation of this strategy is described herein.

We initiated these studies by exploring the addition of ethyl lithio-α-diazoacetate to bicyclic β-lactone (+)-**1a**.[1c] Following several failed attempts to metalate ethyl diazoacetate (EDA) followed by addition of β-lactone (+)-**1a** which led to complex reaction mixtures, we confirmed earlier observations of Moody[11c] that inverse addition of lithium diisopropylamide (LDA) into a THF solution of substrate lactone and EDA at −78 °C was optimal. When applied to β-lactone (+)-**1a**, this provided the desired δ-hydroxyl-α-diazo-β-ketoester (−)-**2a** in 67% yield (Table 1, entry 1). The exclusive chemoselectivity observed with the lithiated diazo ester toward the β-lactone over the geminal methyl esters is noteworthy but not unexpected due to the inherent ring strain of the β-lactone. Compared to the cyclohexyl-fused β-lactone (+)-**1a**, the cyclopentyl-fused bicyclic and tricyclic β-lactones (+)-**1b**[1c] and (±)-**1c**,[6] respectively, required additional equivalents of lithiated EDA (4.0 equiv) for complete conversion (Table 1, entries 2 and 3). Interestingly, reaction with β-lactone (+)-**1b** provided a separable mixture of the expected diazo adduct (−)-**2b** and a α-diazo lactone (+)-**2b′** resulting from subsequent trans-esterification in a 2:1 ratio (Table 1, entry 2).

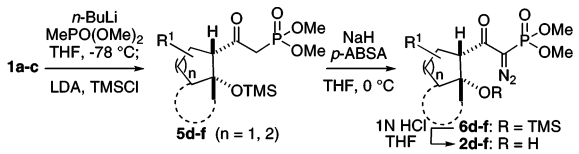
TABLE 1. Acyl C−O Ring Cleavage of Bicyclic and Tricyclic β-Lactones 1a−c to δ-Hydroxy-α-diazo-β-ketoesters 2a−c

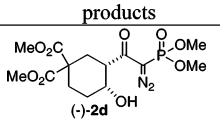
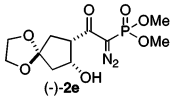
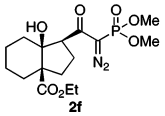


entry	β-lactones	products	% yield[c]
1[a]	 (+)-**1a**	 (-)-**2a**	67
2[b]	 (+)-**1b**	 (-)-**2b** (44%) (+)-**2b'** (20%)	64
3[b]	 (+/-)-**1c**	 (+/-)-**2c**	57

[a] 2.2 equiv of LDA and EDA, 2 h, syringe pump addition of LDA. [b] 4.0 equiv of LDA and EDA, 2 h, syringe pump addition of LDA. [c] Yields refer to isolated, purified (silica gel) product.

TABLE 2. Acyl C−O Ring Cleavage of Bicyclic and Tricyclic β-Lactones 1a−c Leading to δ-Hydroxy-α-diazo β-Phosphonates 2d−f



entry	β-lactones	products	% yield[a]
1	(+)-**1a**	 (-)-**2d**	54
2	(+)-**1b**	 (-)-**2e**	72
3	(±)-**1c**	 **2f**	61

[a] Yields refer to overall yield for three steps of isolated (silica gel), purified product.

δ-Hydroxy-α-diazo-β-ketophosphonates **2d−f** could be synthesized using a simple three-step protocol[11c] involving initial chemoselective β-lactone cleavage with lithiated dimethyl methylphosphonate followed by *in situ* TMS protection of the resulting alkoxide to provide TMS β-keto phosphonate **5** (Table 2).[18] Subsequent diazo transfer with 4-acetamidobenzenesulfonyl azide (*p*-ABSA) and facile desilylation gave δ-hydroxy-α-diazo-β-ketophosphonates **2d−f** in good yield over three steps.

The tandem Wolff rearrangement/lactonization of δ-hydroxy-α-diazo-β-ketoesters and phosphonates **2** was initiated by

(12) For a seminal review of preparations and applications of α-diazo carbonyl compounds, see: Ye, T.; McKervey, A. M. *Chem. Rev.* **1994**, *94*, 1091.

(13) (a) Chantegrel, B.; Deshayes, C.; Faure, R. *Tetrahedron Lett.* **1995**, *36*, 7859. (b) Ronan, B.; Bacqué, E.; Barrière, J. *Tetrahedron* **2004**, *60*, 3819. (c) Liao, M.; Dong, S.; Deng, G.; Wang, J. *Tetrahedron Lett.* **2005**, *47*, 4537.

(14) Paulissen, R.; Reimlinger, H.; Hayez, E.; Hubert, A. J.; Teyssié, P. *Tetrahedron* **1973**, *24*, 2233.

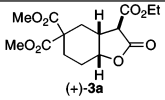
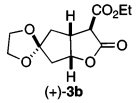
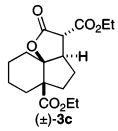
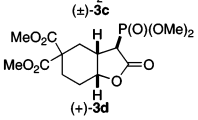
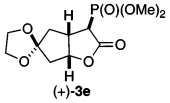
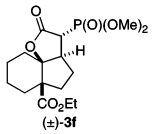
(15) Rapoport, H.; Feldman, P. L.; Moyer, M. P. *J. Org. Chem.* **1985**, *50*, 5223.

(16) For lead references to the synthesis of 3(2*H*)-furanones via O−H insertion, see: (a) Moody, C. J.; Miller, D. J. *Tetrahedron* **1995**, *51*, 10811. (b) Karady, S.; Amato, J. S.; Reamer, R. A.; Weinstock, L. M. *Tetrahedron Lett.* **1996**, *37*, 8277. (c) Albert, P.; Marcus, S. *Tetrahedron Lett.* **1997**, *38*, 5087. (d) Padwa, A.; Sá, M. *J. Braz. Chem. Soc.* **1999**, *10*, 231. (e) Calter, A. M.; Zhu, C. *J. Org. Chem.* **1999**, *64*, 1415. (f) Xu, C.; Zhang, Y.; Yuan, C. *Eur. J. Org. Chem.* **2004**, 2253.

(17) Previous attempts to access a α-diazo-β-keto ester from 4-methyl β-lactone (β-butyrolactone) by with lithiated EDA were unsuccessful, see ref 11b.

(18) Ditrich, K.; Hoffmann, R. W. *Tetrahedron Lett.* **1985**, *26*, 6325.

TABLE 3. Preparation of Bicyclic and Tricyclic α-Carboethoxy or α-Dimethyl Phosphonate γ-Lactones via the Tandem Wolff Rearrangement/Lactonization Process

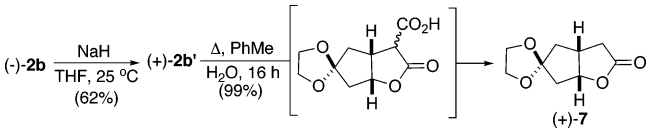
entry	diazo compd	product[a]	photolysis[b] % yield[c] (dr)[d]	thermolysis[e] % yield[c] (dr)[d]
1	(−)-**2a**	 (+)-**3a**	85 (19:1)	78 (8:1); 5[f]
2	(−)-**2b**	 (+)-**3b**	86 (19:1)	51 (6:1); 18[f]
3	(±)-**2c**	 (±)-**3c**	82 (5:1)	--[g]
4	(−)-**2d**	 (+)-**3d**	68 (15:1)	--[g]
5	(−)-**2e**	 (+)-**3e**	52 (12:1)	46 (5:1); 16[f]
6	(±)-**2f**	 (±)-**3f**	86 (10:1)	88 (10:1)[h]; 0[f]

[a] Major diastereomers are shown. The relative stereochemistry of diastereomeric adducts **3a**−**f** was assigned based on nOe measurements and coupling constant analysis ($J_{H2,H3}$; see the Supporting Information for details). [b] Conditions: 254 nm, PhMe, 0.01 M. [c] Yields refer to isolated (silica gel), purified, mixture of diastereomers **3a**−**f**. [d] Diastereomeric ratios determined (^{1}H NMR, 500 MHz) following purification which in all cases led to epimerization. [e] Conditions: 110 °C, PhMe, 0.01 M. [f] Yield of O−H insertion product (i.e., furanone) obtained during thermolysis. [g] Not studied. [h] This reaction was performed with TMS-α-diazo ester **6f** which underwent in situ desilylation (see the Supporting Information for details).

photolysis[19] or thermolysis[13a] to give intermediate ketenes that were efficiently trapped by the pendant alcohol to furnish α-carboethoxy or α-dimethyl phosphonate γ-lactones **3** in good to moderate yields (Table 3). In general, a range of diastereoselectivities was obtained under both photolytic and thermolytic conditions as judged by analysis of crude reaction mixtures; however, this was of no consequence as facile epimerization to the thermodynamically preferred β-epimers occurred upon purification. As indicated, O−H insertion products (5−18%) presumably generated by direct capture of the carbene intermediate with the pendant alcohol during the thermolytic process account for the decreased yields.

Tandem Wolff rearrangement/lactonization with α-diazo-β-phosphonate substrates were less efficient in general (Table 3, entries 4−6). Compromised yields were obtained with α-diazophosphonates (−)-**2d** and (−)-**2e** due to significant intervening O−H insertion observed under both photolytic and thermolytic conditions (Table 3, entries 4 and 5). However, an exception was α-diazo phosphonate (±)-**2f**, which provided the desired product in excellent yield without evidence of O−H insertion product under both photolytic and thermal conditions. Again, minor diastereoisomers of phosphonate esters **3d**−**f** were readily converted to the major diastereomers under mild acidic conditions during silica gel chromatography or treatment with TFA in chloroform.[20] These results indicate that kinetic ratios of diastereomeric adducts are not readily ascertained but that the major diastereomers of **3a**−**f** initially formed are indeed the thermodynamically more stable β-epimers which place the phosphonate or ester moiety in the convex face of the bicycle or tricycle as expected, which is, of course, inconsequential for subsequent transformations, e.g., olefination.

SCHEME 1. Trans-Esterification of α-Diazo Ester (−)-2b to α-Diazo-δ-lactone (+)-2b′ and Tandem Wolff Rearrangement/Decarboxylation to Fused Bicyclic γ-Lactone (+)-7



We also determined that decarboxylated bicyclic γ-lactone (+)-**7** could be synthesized directly from α-diazo-δ-lactone (+)-**2b′**, obtained as a minor product during addition of lithiated EDA to β-lactone (+)-**1b** (see Table 1, entry 2). Furthermore, conversion of α-diazo ester (−)-**2b** to the α-diazo-δ-lactone (+)-**2b′** was accomplished with sodium hydride (Scheme 1). Thermolysis of α-diazo-δ-lactone (+)-**2b′** in wet, boiling toluene provided *cis*-fused bicyclic γ-lactone (+)-**7** in nearly quantitative yield via a tandem Wolff rearrangement/decarboxylation sequence.

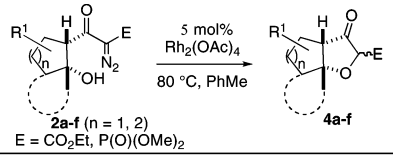
Finally, heating δ-hydroxy-α-diazo-β-ketoesters and β-keto phosphonates **2a**−**f** in the presence of a catalytic amount of rhodium(II) acetate in toluene proceeded efficiently to furnish diastereomeric 3(2*H*)-furanones **4** via a rhodium carbenoid-mediated intramolecular O−H insertion.[15,16] Insertion of δ-hydroxy-α-diazo-β-ketoesters **2a**−**c** proceeded to completion within 10−30 min (Table 4, entries 1−3), while phosphonates (−)-**2d** and (−)-**2e** required 1−2 h for complete conversion (Table 4, entries 4−5). Interestingly, diazo ester (±)-**2f** gave the tandem Wolff rearrangement/lactonization product (±)-**3f** as the predominant product (>60%) under typical O−H insertion conditions. This may be due to steric issues associated with this more congested α-diazo-β-ketophosphonate (±)-**2f**, which retards the rate of metallocarbenoid formation. However, use of the more reactive, electrophilic rhodium catalyst, $Rh_2(OCOCF_3)_4$, promoted the O−H insertion providing the desired 3(2*H*)-furanone (±)-**4f** in excellent yield (Table 4, entry 6). 3(2*H*)-Furanones **4a**−**f** exist as rapidly equilibrating mixtures of *trans* and *cis* diastereomers (∼1:1 dr).[16e,f]

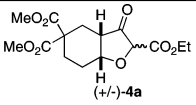
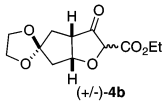
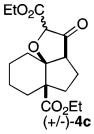
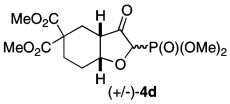
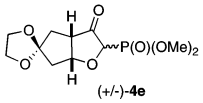
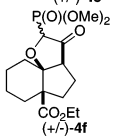
In summary, we developed a strategy for transformation of bicyclic and tricyclic β-lactones to δ-hydroxy-α-diazo-β-ketoesters and δ-hydroxy-α-diazo-β-ketophosphonates. These intermediates were then converted to fused γ-lactones or 3(2*H*)-furanones via a tandem Wolff rearrangement/ lactonization process or a rhodium(II)-catalyzed O−H insertion process, respectively. The reactions reported herein expand the repertoire

(19) (a) Georgian, V.; Boyer, S. K.; Edwards, B. *J. Org. Chem*. **1980**, *45*, 1686. (b) Cossy, J.; Belotti, D.; Leblanc, C. *J. Org. Chem*. **1993**, *58*, 2351.

(20) After silica chromatography, only the major isomer could be isolated. This selective conversion was also confirmed by adding 2 μL of TFA into NMR samples ($CDCl_3$) of crude mixtures of **3e** and **3f** and analyzing by ^{1}H NMR (500 MHz).

TABLE 4. Preparation of α-Carbethoxy or α-Dimethyl Phosphonate 3(2*H*)-furanones via Rhodium(II)-Catalyzed O−H Insertion Reaction



entry	diazo compd	O-H insertion product[a]	% yield[b]
1	(−)-**2a**	 (+/-)-**4a**	99
2	(−)-**2b**	 (+/-)-**4b**	99
3	(±)-**2c**	 (+/-)-**4c**	96
4	(−)-**2d**	 (+/-)-**4d**	92
5	(−)-**2e**	 (+/-)-**4e**	93
6[c]	(±)-**2f**	 (+/-)-**4f**	90

[a] Obtained as rapidly equilibrating mixtures of *trans* and *cis* diastereomers (∼1:1 dr). [b] Yields refer to crude products which did not require further purification with the exception of **4f** which was purified by chromatography (silica gel). [c] $Rh_2(OCOCF_3)_4$ was used as catalyst.

of accessible functional arrays from bicyclic and tricyclic β-lactones to include fused bicyclic and tricyclic γ-lactones and 3(2*H*)-furanones which are common motifs in natural products.

Experimental Section

Representative Procedure for Addition of Lithiated Ethyl Diazoacetate to β-Lactones As Described for Conversion of β-Lactone (+)-1a to α-Diazo Ester (−)-2a. To a solution of ethyl diazoacetate (132 mg, 0.12 mL, 1.16 mmol) and bicyclic β-lactone (+)-**1a** (128 mg, 0.53 mmol) in THF (3.0 mL) at −78 °C was slowly added freshly prepared LDA (3.8 mL, 1.16 mmol, 0.3 M in THF) over 2 h via syringe pump. After 30 min, the reaction was quenched with satd aq NH_4Cl (10.0 mL). The mixture was extracted with Et_2O (3 × 20 mL). The dried ($MgSO_4$) extract was concentrated in vacuo and purified by flash chromatography, eluting with EtOAc/hexanes (20:80) to give α-diazo ester (−)-**2a** (126 mg, 0.36 mmol, 67%) as a yellowish oil: $[\alpha]^{23}_D$ −23.3 (*c* 0.60, $CHCl_3$); IR (thin film) 3512 (br), 2956, 2140, 1709, 1650, 1434, 1378, 1280 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 4.31 (dq, *J* = 1.0, 7.0 Hz, 2H), 4.17−4.20 (m, 1H), 3.81 (s, 3H), 3.73 (s, 3H), 3.68 (dt, *J* = 1.5, 13.0 Hz, 1H), 3.43 (s, 1H), 2.40 (t, *J* = 13.0 Hz, 1H), 2.11−2.23 (m, 3H), 1.86−1.96 (m, 1H), 1.78−1.84 (m, 1H), 1.34 (dt, *J* = 1.0, 7.0 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 196.4, 172.3, 171.4, 160.6, 65.2, 61.9, 54.1, 53.0, 52.9, 45.6, 29.0, 27.2, 24.6, 14.6; HRMS (ESI+) calcd for $C_{15}H_{20}N_2O_8Li$ (M + Li) 363.1380, found 363.1424.

Representative Procedure for Tandem Wolff Rearrangement/Lactonization As Described for Conversion of α-Diazo Ester (−)-2a to γ-Lactone (+)-3a. A solution of (−)-**2a** (15 mg, 0.04 mmol) in PhMe (5.3 mL) was irradiated for 16 h at 254 nm. After evaporation, the crude material was purified by flash chromatography, eluting with EtOAc/hexanes (20:80), to give (+)-**3a** (12 mg, 0.036 mmol, 85%) as a colorless oil: $[\alpha]^{23}_D$ +17.0 (*c* 0.47, $CHCl_3$); IR (thin film) 2954, 1785, 1729, 1439, 1258, 1172 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 4.80 (q, *J* = 3.5 Hz, 1H), 4.25 (q, *J* = 7.5 Hz, 2H), 3.80 (s, 3H), 3.75 (s, 3H), 3.27 (d, *J* = 1.5 Hz, 1H), 2.95−2.99 (m, 1H), 2.44 (ddd, *J* = 2.0, 6.0, 14.0 Hz, 1H), 2.17−2.24 (m, 2H), 1.97 (dt, *J* = 4.5, 9.0 Hz, 1H), 1.72−1.82 (m, 1H), 1.58 (dd, *J* = 6.5, 14.0 Hz, 1H), 1.33 (t, *J* = 7.5 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 171.7, 171.6, 170.8, 166.9, 77.1, 62.6, 55.9, 53.5, 53.3, 53.1, 37.0, 31.2, 24.6, 23.9, 14.3; HRMS (ESI+) calcd for $C_{15}H_{20}O_8Li$ (M + Li) 335.1318, found 335.1391.

Representative Procedure for the O−H Insertion Process As Described for Conversion of α-Diazo Ester (−)-2a to 3(2*H*)-Furanone (±)-4a. To a solution of $Rh_2(OAc)_4$ (∼0.75 mg, 1.7 μmol) in PhMe (1.7 mL) at 80 °C was added a solution of (−)-**2a** (12 mg, 0.034 mmol) in PhMe (1.7 mL) dropwise. After 5 min, the reaction was cooled to 25 °C and filtered through a plug of Celite. Concentration by rotary evaporation gave 3(2*H*)-furanone (±)-**4a** as an inseparable mixture of α-diastereomers (11 mg, 0.033 mmol, 99%) as a clear, colorless oil that did not require further purification: IR (thin film) 2972, 1744, 1225, 1104, 1019 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 4.71 (s, 0.5H), 4.61 (q, *J* = 3.5 Hz, 0.5H), 4.45 (s, 0.5H), 4,24−4,32 (m, 2.5H), 3.77 (s, 3H), 3.74 (s, 1.5H), 3.73 (s, 1.5H), 2.68−2.77 (m, 1H), 2.42 (ddd, *J* = 1.0, 7.0, 14.0 Hz, 0.5H), 2.30 (ddd, *J* = 1.0, 7.0, 14.0 Hz, 0.5H), 2.15−2.27 (m, 2.5H), 2.05 (dt, *J* = 5.0, 14.0 Hz, 0.5H), 1.85 (dd, *J* = 12.5, 17.5 Hz, 0.5H), 1.77−1.84 (m, 1H), 1.71 (dd, *J* = 12.5, 17.5 Hz, 0.5H), 1.33 (t, *J* = 7.0 Hz, 1.5 H), 1.27 (t, *J* = 1.5H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 208.8, 208.5, 171.8, 171.6, 170.8, 170.7, 166.7, 165.7, 80.9, 79.4, 74.9, 73.8, 62.5, 62.4, 53.21, 53.18, 53.15, 53.07, 53.03, 53.01, 43.5, 43.2, 27.2, 26.4, 25.0, 24.9, 24.0, 23.9, 14.4, 14.3; HRMS (ESI+) calcd. for $C_{15}H_{21}O_8$ (M + H) 329.1236, found 329.1288.

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Supporting Information Available: Experimental details and full characterization of all new compounds. This material is available free of charge via the Internet at http://pubs.acs.org.

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