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Metallo-Esterification of Alkynes: Reaction of Alkynes with Cp_2ZrEt_2 and Chloroformate

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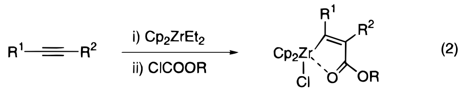
Carbometalation of alkynes is a very attractive reaction for the preparation of stereodefined substituted olefins.[1] Among olefins, α,*β*-unsaturated ester is one of the most useful compounds in organic synthesis. Metallo-esterification of alkynes is a simple and direct preparative method of such stereodefined substituted metallo-propenoates **1** (eq 1), which can be converted into variously functionalized α,*β*-unsaturated esters. However, there is no procedure for metallo-esterification of alkynes, although chloro-esterification[2] and hydro-esterification of alkynes[3,4] and acyl-metalation[5−7] have been reported.

(1)

1

In this paper, we report metallo-esterification of alkynes based on the reaction of alkynes with Cp_2ZrEt_2 and chloroformate (eq 2). Moreover, the resulting metallo-esterification product **2** further reacted with various electrophiles to form highly substituted propenoates (Scheme 1).



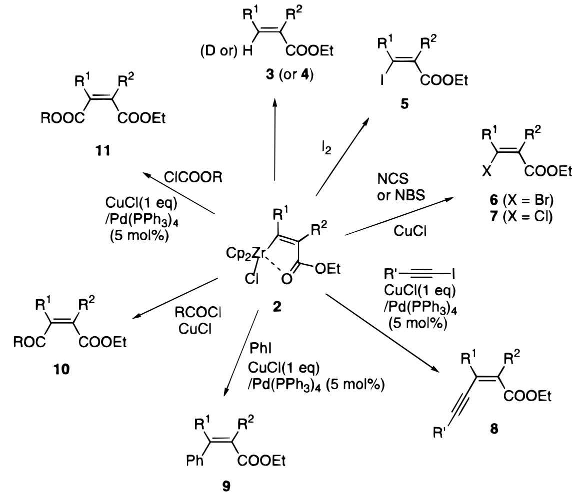
(2)

2

2a: R^1, R^2 = Ph, R = Et
2b: R^1, R^2 = Ph, R = Me

A zircono-esterification product of diphenylacetylene **2a** was formed in 95% NMR yield. The ^{1}H NMR spectrum of **2a** showed a singlet signal at 5.97 ppm assigned to Cp protons. In its ^{13}C NMR spectrum, Cp carbons appeared at 111.92 ppm and three sp^2 carbons appeared at 179.56, 151.04, and 137.04 ppm, assignable to Zr−*C*(Ph)=, −*C*(=O)OEt, and −C(Ph)=*C*(Ph)-C, respectively.

Scheme 1



Hydrolysis of **2a** with 3 N HCl gave ethyl-(*E*)-2,3-diphenylpropenoate **3a** in 93% yield. Deuteriolysis and iodinolysis instead of hydrolysis of **2a** afforded the monodeuterated compound **4a** in 95% yield with 91% deuterium incorporation and monoiodinated product **5a** in 90% yield, respectively.

To confirm the structure of the zircono-esterification product **2**, white crystals of **2b** ($R^1 = R^2 =$ Ph, R = Me) suitable for X-ray analysis were obtained at −40 °C in THF. The structure of **2b** is shown in Figure 1. It clearly shows the formation of zircono-esterification product of diphenylacetylene and also reveals the coordination of the carbonyl group to the zirconium metal center.

The zircono-esterification products of alkynes could be converted into functionalized stereodefined α,*β*-unsaturated esters by coupling with various electrophiles such as acyl chlorides,[10] iodobenzene,[11] alkynyl iodide,[12] NCS and NBS[13] in the presence of a catalytic amount of $Pd(PPh_3)_4$ and/or CuCl.[14] The various

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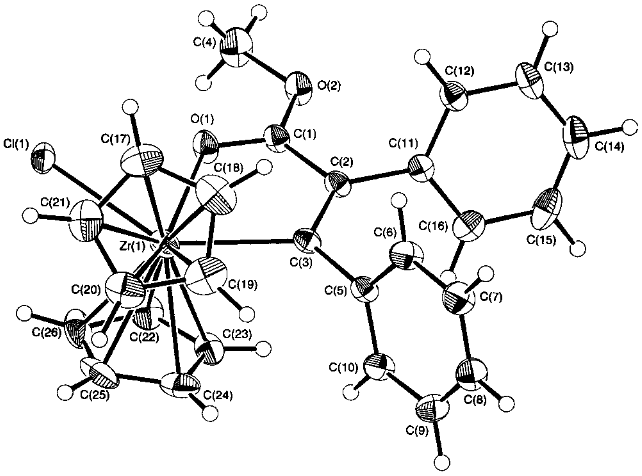


Figure 1. Structure of **2b**. Selected bond lengths (Å) and angles (deg) are Zr(1)−C(3), 2.432(4); Zr(1)−O(1), 2.237(3); Zr(1)−Cl(1), 2.646(1); C(1)−O(1), 1.247(5); C(1)−O(2), 1.314; C(1)−C(2), 1.447(6); C(2)−C(3), 1.370(6); O(1)−Zr(1)−C(3), 69.0(1); Cl(1)−Zr(1)−O(1), 70.34(9); Zr(1)−C(3)−C(2), 114.9(3); C(1)−C(2)−C(3), 112.4(4).

Scheme 2

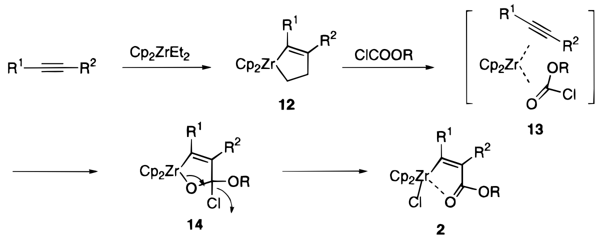
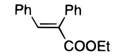
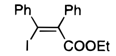
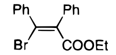
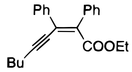
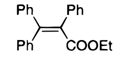
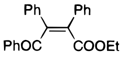
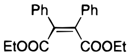
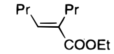
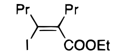
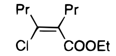
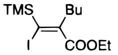
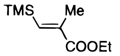
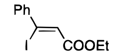


Table 1. Preparation of Functionalized Propenoate by the Reaction of Alkynes with Cp_2ZrEt_2 and Electrophiles

Alkyne	Electrophile	Temp. (°C)	Time (h)	Product		Yield (%)[a]
Ph—≡—Ph	HCl	rt	6		**(3a)**	93 (70)
Ph—≡—Ph	I_2	rt	1		**(5a)**	90 (68)
Ph—≡—Ph	NBS	rt	1		**(6a)**	76 (70)
Ph—≡—Ph	Bu—≡—I	50	6		**(8a)**	49 (45)
Ph—≡—Ph	PhI	50	1		**(9a)**	- (65)
Ph—≡—Ph	PhCOCl	50	1		**(10a)**	91 (62)
Ph—≡—Ph	ClCOOEt	50	3		**(11a)**	40 (31)
Pr—≡—Pr	HCl	rt	1		**(3c)**	87 (67)
Pr—≡—Pr	I_2	rt	12		**(5c)**	94 (76)
Pr—≡—Pr	NCS	rt	1		**(7c)**	90 (75)[b]
TMS—≡—Bu	I_2	rt	12		**(5d)**	78 (57)
TMS—≡—Me	HCl	rt	1		**(3e)**	65 (61)
Ph—≡—H	I_2	rt	12		**(5f)**	44 (31)

[a] GC yields; isolated yields are given in parentheses. [b] Cp_2ZrEt_2 was prepared using EtMgCl instead of EtMgBr.

reactions are summarized in Scheme 1, and the representative results are shown in Table 1. The hydro-esterification products **3** were obtained in good to high yields after hydrolysis of **2**. The bromo-esterification product **6a** was prepared in 76% yield by bromination of **2a** with NBS in the presence of CuCl. It is notable that the use of NCS afforded a bromination product, but not a chlorination product. Halogen-exchange reaction occurred during the reaction. To obtain the chlorination product **7c**, EtMgCl has to be used instead of EtMgBr. The reaction of **2a** with iodobenzene in the presence of CuCl and a catalytic amount of $Pd(PPh_3)_4$ gave the corresponding cross-coupling product **9a** in 65% isolated yield. The reaction of **2a** with benzoyl chloride afforded ketoester **10a** in 91% yield. When **2a** was treated with additional chloroformate in the presence of CuCl and a catalytic amount of $Pd(PPh_3)_4$, maleate derivative **11a** was obtained in moderate yield.

A proposed mechanism of this reaction is shown in Scheme 2. It was reported that the reaction of Cp_2ZrEt_2, which is in situ converted to $Cp_2Zr(CH_2{=}CH_2)$,[8] with alkynes gave zirconacyclopentenes **12** in excellent yields.[9] The ethylene moiety of zirconacyclopentene compounds could be easily replaced by various unsaturated compounds.[15] Herein, chloroformate was chosen to be used as the unsaturated compound whereby it is possible to provide an ester group. The ethylene moiety of zirconacyclopentene **12** can be replaced by chloroformate to give oxazirconacyclopentene **14** via **13** by either a dissociative or an associative path.[15c] Then, elimination of chloride from oxazirconacyclopentene **14** takes place to form the zircono-esterification product of alkynes **2**.

Alternatively, the mechanism which involves oxidative addition of ClCOOR to a zirconocene alkyne complex $Cp_2Zr(R^1CCR^2)$ giving $Cp_2ZrCl(COOR)(R^1CCR^2)$ and the subsequent migratory insertion of the alkyne into the Zr−COOR moiety to afford **2** cannot be ruled out.

Further investigations on metallo-esterification of alkynes are now in progress.

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Supporting Information Available: Experimental details and spectroscopic characterization of compounds, and structures, tables of crystallographic data, atomic coordinates, thermal parameters and bond lengths and angles for **2b** (PDF). This material is available free of charge via the Internet at http://pubs.acs.org.

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