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The Gold-catalyzed Formal Hydration, Decarboxylation, and [4+2] Cycloaddition of Alkyne Derivatives Featuring L_2/Z-type Diphosphinoborane Ligands

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The catalytic formal hydration of alkynes and decarboxylation of alkynoic acid were developed using a Au catalyst featuring a Z-ligand. Furthermore, the intramolecular [4+2] cycloaddition of the alkynoic acid-alkene derivative for the formation of the oxabicyclo[4.4.0] skeleton also proceeded.

Keywords: Z-Ligand | Gold | Catalytic reaction

For organometallic compounds, there are three types of ligands, the L-, X- and Z-types categorized by Green.[1] Although the X-ligand forming a covalent bond with a metal (M-X) and L-ligand providing two electrons to a metal (M←:L) are generally used, the σ-acceptor type Z-ligand (M:→Z) metal complexes and their catalytic reactions are still limited.[2–7] We recently focused on the syntheses of the gold(I) complexes Au(DPB^R)X **1** featuring a Z-type ligand (boron atom) and its applications to catalytic reactions. The Z-Au catalysts were effective for the construction of 7-membered ring systems not only from enynes but also from yne-diols **2** (Figure 1).[8] Based on the previous study, the interaction between the boron atom of the Z-ligand and oxygen atom of the alcohol was detected by the ^{11}B NMR shift, which suggested activating of the reactivity of the O atom by chelation assistance.[8b] Based on this, we speculated that the chelation assistance of the Z-ligand might activate the reactivities of the other oxygen atoms, such as the intermolecular alcohol or intramolecular carboxylic acid, for the catalytic reactions. We now report the catalytic formal hydration, decarboxylation, and formal [4+2] cycloaddition by using alkynes and oxygen atoms featuring the Z-type ligand.

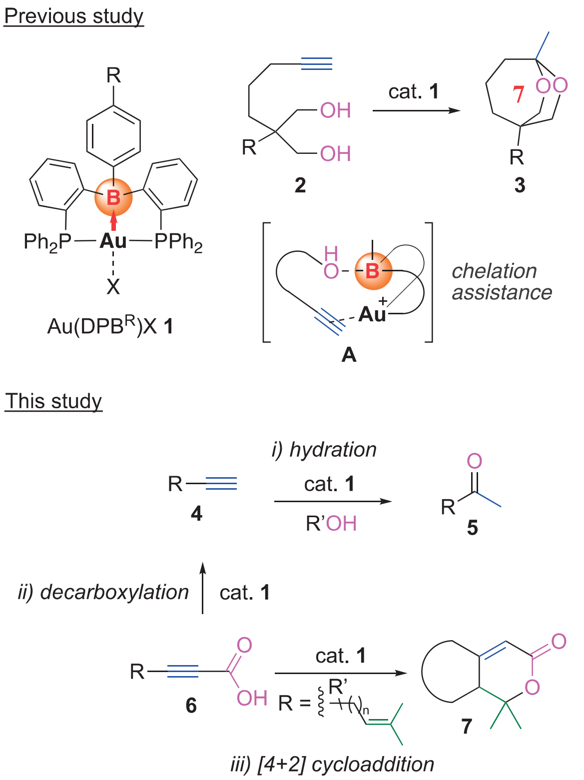
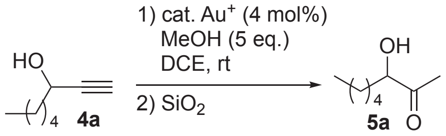
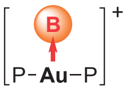


Figure 1. Catalytic reactions of alkynes and oxygen atom featuring Au(DPB^R)X **1**.

The metal-catalyzed formal hydration of alkynes is one of the most important reactions for making the ketone unit. As a representative metal species, Hg(II) is well known for the hydration reaction. However, there is a significant disadvantage of being toxic. For avoiding the use of a mercury salt, the hydrations using Au,[9] Pt,[10] Ru[11] or Ag[12] have been explored. In most cases of hydration reactions using Au(I) catalysts, a high reaction temperature is required. For example, hydration with gold catalysts bearing NHC ligands is conducted at 50–120 °C.[9d,9l,9m] Only one example of the NHC-Au catalyzed hydration using 3-hexyne at room temperature was recently reported by Zuccaccia *et al*. Also, Hu and Wu's group reported the hydration of alkynes at room temperature with a Au catalyst bearing isocyanide ligands. Although the reactions were effective for several arylalkynes and alkylalkynes, the addition of a large amount of -OH sources as the solvents, such as MeOH and water, must be required. Therefore, developing more effective gold catalysts for the alkyne hydration at room temperature is still a challenging task. At the beginning, the addition of 4 mol % of Au(DPB)SbF$_6$ (L_2/Z-type ligands) to the solution of octyn-3-ol (**4a**) and MeOH (5 equiv) in DCE at room temperature for 24 h followed by hydrolysis gave the desired ketone **5a** in 87% yield (Table 1, Entry 1). When the

Table 1. Au(I)-catalyzed formal hydration of alkyne **4a**

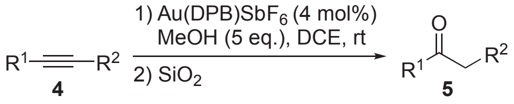


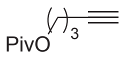
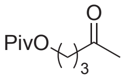
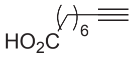
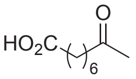
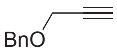
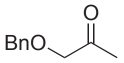
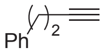
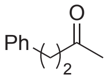
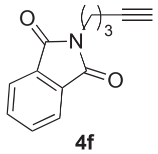
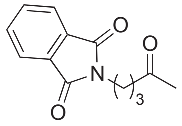
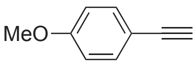
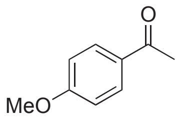
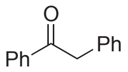
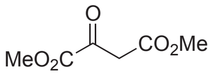
entry	Au cat.	form	time	yield
1	Au(DPB)SbF$_6$		24 h	87%
2	Au(PPh$_3$)$_2$SbF$_6$	$[\mathrm{P{-}\mathbf{Au}{-}P}]^+$	24 h	trace
3	Au(PPh$_3$)SbF$_6$	$[\mathrm{P{-}\mathbf{Au}}]^+$	1.5 h	41%

$Au(PPh_3)_2SbF_6$ (L_2-type ligands), which did not contain the boron atom at the ligand, was treated, the reaction hardly proceeded (Entry 2). Carriedo *et al.* reported the hydration with the bis(phosphine) gold(I) cation at high temperature (100–150 °C). These results suggest that the σ-acceptance of Z-ligand would activate the formal hydration. Although the reaction with $Au(PPh_3)SbF_6$ was much faster than the others, the product **5a** was obtained in moderate yield (41%, Entry 3).

Our next effort focused on the exploration of the scope and limitations. These results are summarized in Table 2. When the 4-pentynyl pivalate (**4b**) was treated under the best conditions in Table 1, the desired product **5b** (96%) was observed in high yield (Entry 1). The alkyne **4c** bearing carboxylic acid was also applicable for the formal hydration, which provided **5c** in 92% yield (Entry 2). The reactions with benzyloxymethyl, phenethyl, and *N*-protected aminopropyl alkynes **4d**–**f** provided the desired ketones **5d**–**f** in moderate yields (Entries 3–5). Formal hydration with 4-methoxyphenylacetylene (**4g**) gave the arylmethylketone **5g** (87%) in good yield (Entry 6). On the other hand, internal alkynes **4h**,**i** bearing phenyl or ester moieties did not afford the desired products **5h**,**i** (Entries 7 and 8).

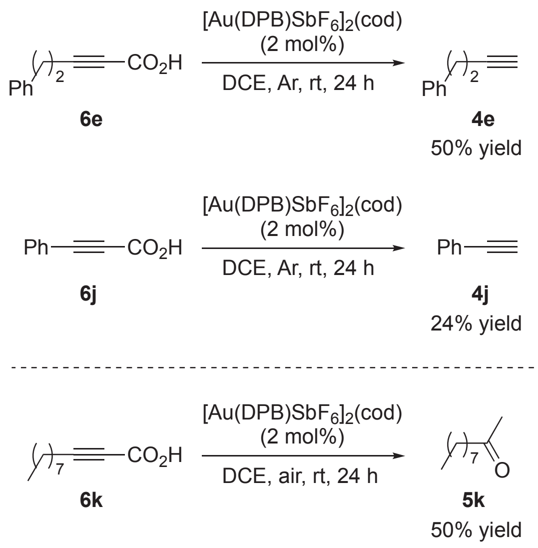
Table 2. $Au(DPB)SbF_6$-catalyzed formal hydration of alkynes **4**.



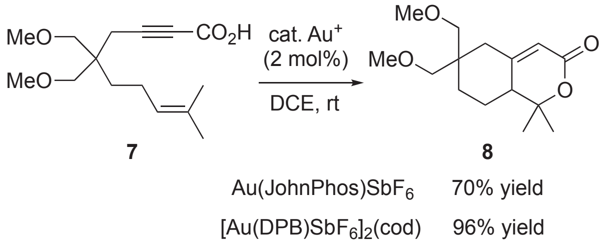
entry	substrate	result
1	 **4b**	 **5b**: 8 h, 96%
2	 **4c**	 **5c**: 3.5 h, 92%
3	 **4d**	 **5d**: 18 h, 55%
4	 **4e**	 **5e**: 24 h, 60%
5	 **4f**	 **5f**: 24 h, 69%
6	 **4g**	 **5g**: 18 h, 87%
7	Ph—≡—Ph **4h**	 **5h**: 24 h, no reaction
8	MeO_2C—≡—CO_2Me **4i**	 **5i**: 24 h, complex mixture

Carboxylic acids, which are present in many natural products and commercially available compounds, are interesting functional groups that lead to various reactions including the classical decarboxylation of β-dicarboxylic acid by heating. Recently, several types of catalytic decarboxylations of aryl-carboxylic acids have been reported by using Cu,[13] Ag,[14] and Au[15] under heating conditions. However, the decarboxylation of alkynoic acid is still limited. Kolarovič and co-worker[16] reported the Pd or Cu-catalyzed decarboxylation of alkynoic acid at 60 °C. Also, Pd-catalyzed decarboxylative coupling of alkynoic acids and aryl halides was reported by several groups.[17] However, as far as we know, the reaction requires on elevated temperature. After several screenings, we found that the treatment of 2 mol % of $[Au(DPB)SbF_6]_2(cod)$ and alkynoic acid **6e** in DCE under Ar afforded the decarboxylative product **4e** (50%) in moderate yield at room temperature (Scheme 1). Although decarboxylation of arylalkynoic acid **6j** also gave the desired product **4j**, the chemical yield (24%) was rather low. When the alkylalkynoic acid **6k** was treated with the same catalyst in air, the product was not the terminal alkyne but a ketone **5k** (50% yield). Decarboxylation and hydration with moisture would give the resulting ketone **5k**.

Our final task in this research was the intramolecular [4+2] cycloaddition of the alkynoic acid-alkene. In 2012, Yu and Shin's group[18] reported the $Au(JohnPhos)SbF_6$-catalyzed intermolecular [4+2] cycloaddition of alkynoic acid and alkene to form the α,β-unsaturated δ-lactone. However, the intramolecular [4+2] cycloaddition is unreported. When the alkynoic acid-alkene derivative **7** was treated with 2 mol % of



Scheme 1.



Scheme 2.

$Au(JohnPhos)SbF_6$, the desired oxabicyclo[4.4.0] derivative **8** was observed in 70% yield (Scheme 2). For the reaction with $[Au(DPB)SbF_6]_2(cod)$, the cyclized product **8** was provided in a better yield (96%).

In summary, we found that the Au catalyst featuring the Z-ligand worked not only for the formal hydration of alkynes, but also the decarboxylation of alkynoic acid at room temperature. In addition, the intramolecular [4+2] cycloaddition of the alkynoic acid-alkene derivative for the formation of the oxabicyclo[4.4.0] skeleton was also developed by using the Z-Au catalyst. Further investigation of the intramolecular [4+2] cycloaddition is currently in progress.

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Supporting Information is available on http://dx.doi.org/10.1246/cl.180610.

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