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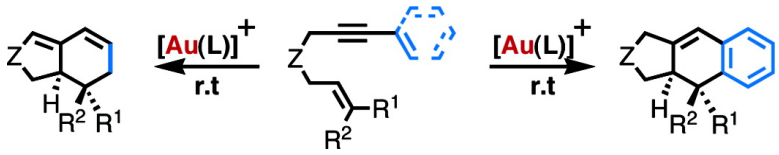

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Intramolecular [4 + 2] Cycloadditions of 1,3-Enynes or Arylalkynes with Alkenes with Highly Reactive Cationic Phosphine Au(I) Complexes

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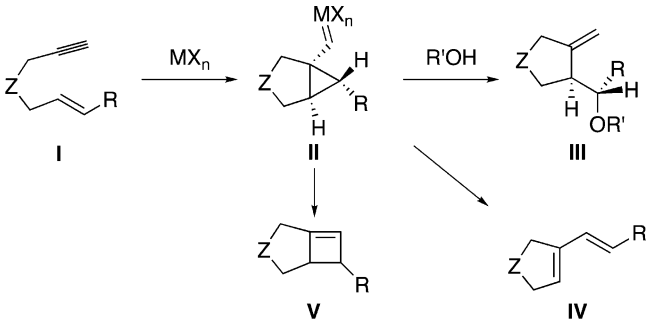
Enynes **I** cyclize by a 5-*exo*-*dig* pathway with electrophilic transition metal complexes or halides MX_n as catalysts to give a variety of cycloisomerization and addition derivatives via metal cyclopropyl carbenes **II** as intermediates (Scheme 1).[1,2] Thus, reaction with nucleophiles R′OH (alcohols or water) gives products of type **III**,[1,2] whereas in the absence of nucleophiles, dienes **IV** by skeletal rearrangement or, less commonly, cyclobutenes **V** can be obtained.[1,3]

Scheme 1



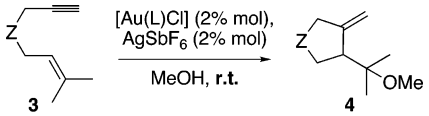
For some of these transformations, complexes [Au(PPh$_3$)]X proved to be the most reactive catalysts.[4] However, enynes bearing substituted alkynes, in particular, those with an aryl group, are quite reluctant to undergo cycloisomerization and alkoxycyclization reactions.[4a] In accordance to that found in certain Pd-catalyzed reactions,[5] we reasoned that higher reactivity could be achieved by using bulkier phosphines as ligands for Au(I). We now report that gold(I) complexes bearing bulky, biphenyl-based phosphines[6] catalyze at room temperature the intramolecular [4 + 2] cycloadditions of enynes substituted at the alkyne with an alkenyl or an aryl group to give hydrindanes or linearly fused tricyclic systems, respectively.

To compare the catalytic efficiency of these new catalysts, we assayed the methoxycyclization of 1,6-enyne **3** to give ether **4**[2,4a] (Table 1). The reaction proceeds with a variety of [Au(L)Cl] complexes where L = PPh$_3$ (Table 1, entry 1), PCy$_3$, P(C$_6$F$_5$)$_3$, or AsPh$_3$ in 3−5 h to give **4** in similar yields.[7] However, reaction of **3** with [Au(L)Cl] complexes with bulkier P(*o*-Tol)$_3$ or P(1-Naphth)$_3$ led to slower reactions (Table 1, entries 2 and 3). Remarkably, complexes **1a**−**d** gave **4** in 15−30 min (Table 1, entries 4 and 5). Au(I) complexes with N-heterocyclic donor ligands **2a**−**c**[8] are less active (Table 1, entries 6−8).

1,8-Dien-3-yne **5a** cyclizes by a 5-*exo*-*dig* pathway[9] to give hydrindane **6a** with **1a** as catalyst (Scheme 2). Similarly, **5b** gives a mixture of regioisomeric dienes **6b** and **7**. The reaction presumably proceeds through intermediate **VI**, which undergoes ring expansion in a process that is reminiscent of the Nazarov cyclization to form allyl cation **VII**. This is followed by loss of a proton followed by protodemetalation to give dienes **6a**,**b** and **7**.[10]

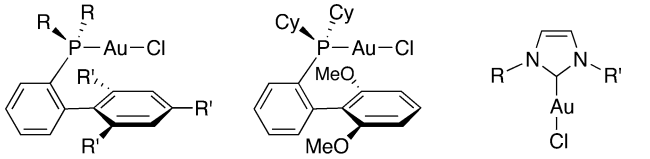
Involvement of **VI** in the cyclization is supported by the isolation of **8**, the product of a 5-*exo*-*dig* methoxycyclization, when the reaction of **5a** was carried out in MeOH as solvent with catalyst **1a** (eq 1).

Table 1. Au(I)-Catalyzed Methoxycyclization of Enyne **3** with Different Au(I) Complexes (Z = C(CO$_2$Me)$_2$)[a]



entry	[Au(I)]	time (h)	yield (%)
1	[Au(PPh$_3$)Cl]	3	84
2	[Au(P(*o*-Tol)$_3$)Cl]	24	90
3	[Au(P(1-Naphth)$_3$)Cl]	18	76
4	**1a**	*0.5*	*97*
5	**1b**−**d**	*0.25*	*89*−*92*
6	**2a**	1.5	71
7	**2b**	5	87
8	**2c**	24	34

[a] Reaction times correspond to >98% conversions of **3** (determined by GC).

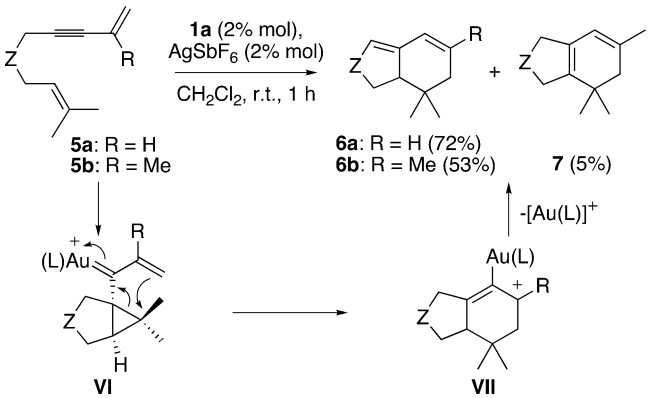


1a: R = Cy, R' = H
1b: R = *t*-Bu, R' = H
1c: R = Cy, R' = *i*-Pr

1d

2a: R = R' = Mes
2b: R = Mes, R' = Me
2c: R = R' = Me

Scheme 2. Au(I)-Catalyzed Cyclization of 1,8-Dien-3-ynes **5** (Z = C(CO$_2$Me)$_2$)



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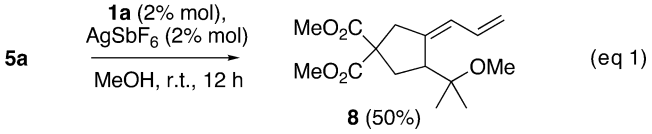
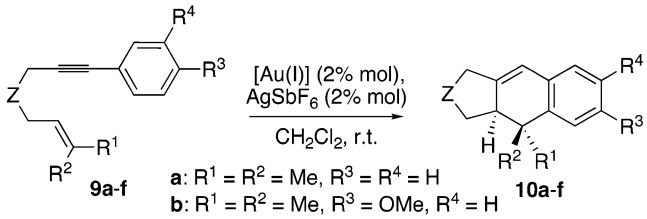


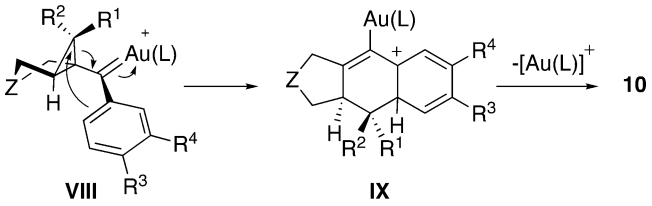
Aryl-substituted enynes **9a**−**f** react with catalysts **1a**−**d** to give 2,3,9,9a-tetrahydro-1*H*-cyclopenta[*b*]naphthalenes **10a**−f [11] in good yields by intramolecular [4 + 2] cycloadditions (Table 2). Cyclization with $[Au(PPh_3)]SbF_6$ requires longer reaction times (Table 2, entry 2). In the case of **9c**, the aryl group reacts at the least substituted position to give **10c** (Table 2, entry 4). On the other hand, **10d**−**f** are obtained as single stereoisomers, as a result of retention of the alkene configuration. Although satisfactory results are obtained with **1a** or **1b**, complex **1d** is the precatalyst of choice for the cyclization of the less reactive substrates.

Table 2. Au(I)-Catalyzed Cyclization of **9a**−**f** (Z = $C(CO_2Me)_2$)



entry	enyne	[Au(I)]	time (h)	product	yield (%)
1	**9a**	**1a**	1	**10a**	86
2	**9a**	$[Au(PPh_3)Cl]$	12	**10a**	83
3	**9b**	**1d**	12	**10b**	96
4	**9c**	**1d**	3	**10c**	53
5	**9d**	**1a**	12	**10d**	43
6	**9d**	**1d**	12	**10d**	67
7	**9e**	**1a**	36	**10e**	51
8	**9e**	**1b**	20	**10e**	45
9	**9e**	**1d**	18	**10e**	76
10	**9f**	**1d**	48	**10f**	64

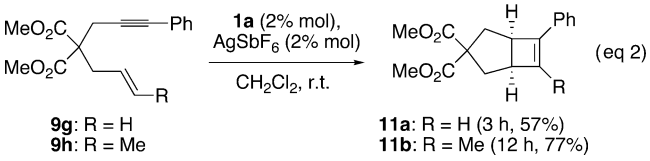
Scheme 3. Proposed Mechanism for the Au(I)-Catalyzed Cyclization of Enynes **9a**−**f** (Z = $C(CO_2Me)_2$)



Cyclization of enynes **9a**−**f** follows a 5-*exo*-*dig* pathway to form cyclopropyl Au(I) carbene **VIII** (Scheme 3), which then probably evolves by a Nazarov-type cyclization to form **IX**. This transformation can also be view as an opening of the cyclopropane of **VIII** by the electron-rich aryl ring.

Enynes **9g**,**h** give **11a**,**b** under these conditions (eq 2), which suggests that the transformation of Scheme 3 proceeds with substrates bearing alkenes substituted at the terminal position with groups capable of stabilizing the developing positive charge. Cyclobutenes related to **11** had been obtained by Trost using palladacyclopentadienes as catalysts.[3a,b]

In summary, we have found novel reactivity of substituted 1,6-enynes by using highly alkynophilic Au(I) complexes **1a**,**d** with



biphenyl phosphines as ligands. Best results are obtained with complex **1d**, which bears an electron-rich aryl ring. While thermal intramolecular [4 + 2] cycloadditions (dehydro-Diels−Alder reactions) of enynes with alkenes only take place at high temperatures,[12] these transformations proceed with Au(I) catalysts under mild conditions to provide bi- or tricyclic ring systems.

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Supporting Information Available: Additional experiments and characterization data. This material is available free of charge via the Internet at http://pubs.acs.org.

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