Organometallics **1993,** *12,* 261-262

A Copper(I) Catalyst for Carbene and Nitrene Transfer To Form Cyclopropanes, Cyclopropenes, and Aziridines

Pedro J. Pérez, M. Brookhart,* and J. L. Templeton*

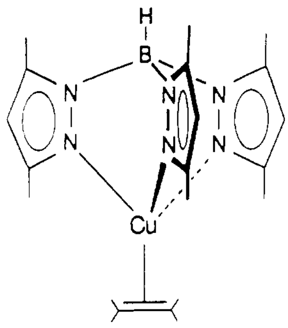
Department of Chemistry, The University of North Carolina at Chapel Hill, Chapel Hill, North Carolina 27599-3290

Received November 4, 1992

Summary: The copper(I) complex Tp′Cu(C_2H_4) (1; Tp′ = hydrotris(3,5-dimethyl-1-pyrazolyl)borate) catalyzes reactions of ethyl diazoacetate with alkenes or alkynes to form cyclopropanes or cyclopropenes, respectively. Yields are moderate to high, and the reactions are performed under mild conditions. Complex 1 also catalyzes nitrene transfer from PhI═NTs to alkenes to produce aziridines in high yield.

Metal-catalyzed carbene transfer reactions provide a useful route to cyclopropanes[1,2] and cyclopropenes.[1,3] During the past decade several groups have reported systems capable of such transformations. Palladium-, rhodium-, and copper-based systems are reported to be the most efficient,[1] with regard to both yields and diastereo- and enantioselectivity. Thus, chiral rhodium carboxamides have been employed in asymmetric olefin cyclopropanation[4a,b] and alkyne cyclopropenation[4c] reactions; chiral rhodium porphyrin complexes are also effective catalysts for similar transformations.[5,6] Copper(I) reagents are now being studied as catalysts in combinations with chiral organic ligands such as salicylaldehyde derivatives,[7] oxazolines,[8] semicorrins,[9] and polypyrazoles.[10] Asymmetric cyclopropanation has been achieved in moderate to high yields with these catalysts. The use of traditional copper species as catalyst precursors for cyclopropenation requires high temperatures (90–140 °C) while yields are moderate to low.[3]

In contrast, development of related synthetic routes to aziridines by metal-to-olefin nitrene transfer has received little attention. Benzenesulfonyl azide decomposes in the presence of Cu(0) and cyclohexene to form an aziridine product in very low yield.[11] Iron porphyrins catalyze the N-tosylaziridination of alkenes in moderate yields.[12] Cu(I) and Cu(II) species are known to catalyze olefin aziridination with PhI═NTs as the nitrene source.[13] Very recently, a Cu(I)–oxazoline system has been reported which promotes almost quantitative asymmetric aziridination of styrene.[8a] We now wish to present results which show that Tp′Cu(C_2H_4) (1; Tp′ = hydrotris(3,5-dimethyl-1-pyrazolyl)borate)[14] is a highly efficient catalyst, under mild conditions, for carbene transfer from ethyl diazoacetate to alkenes and alkynes to form cyclopropanes and cyclopropenes. Furthermore, complex 1 also catalyzes, again under mild conditions, nitrene transfer from PhI═NTs to alkenes to produce aziridines.



1

In a typical experiment,[15] styrene was converted into ethyl 2-phenyl-1-cyclopropanecarboxylate by using ethyl diazoacetate (EDA) as the carbene source and a catalytic amount of Tp′Cu(C_2H_4) (1 mol % based on EDA), as depicted in eq 1. Diethyl fumarate and maleate (5:1 ratio) were obtained as byproducts resulting from carbene dimerization. Formation of these diesters can be diminished by increasing the olefin:EDA ratio and by performing particularly slow addition of EDA. Table I shows the

(1)

2a

---

(1) Maas, G. *Top. Curr. Chem.* **1987,** *137,* 75.

(2) Doyle, M. P. *Chem. Rev.* **1986,** *86,* 919.

(3) Protopopova, M. N.; Shapiro, E. A. *Russ. Chem. Rev.* (*Engl. Transl.*) **1989,** *58,* 667.

(4) (a) Doyle, M. P.; Bagheri, V.; Wandless, T. J.; Harn, N. K.; Brinker, D. A.; Eagle, C. T.; Loh, K.-L. *J. Am. Chem. Soc.* **1990,** *112,* 1906. (b) Doyle, M. P.; Brandes, B. D.; Kazala, A. P.; Pieters, R. J.; Jarstfer, M. B.; Watkins, L. M.; Eagle, C. T. *Tetrahedron Lett.* **1990,** *31,* 6613. (c) Protopopova, M. N.; Doyle, M. P.; Müller, P.; Ene, D. *J. Am. Chem. Soc.* **1992,** *114,* 2755.

(5) (a) Maxwell, J. L.; O'Malley, S.; Brown, K. C.; Kodadek, T. *Organometallics* **1992,** *11,* 645. (b) O'Malley, S.; Kodadek, T. *Tetrahedron Lett.* **1991,** *32,* 2445. (c) Relevant mechanistics studies using rhodium-porphyrin catalysts have been recently reported: Maxwell, J. L.; Brown, K. C.; Bartley, D. W.; Kodadek, T. *Science* **1992,** *256,* 1544.

(6) Callot, H. J.; Metz, F.; Piechoki, C. *Tetrahedron* **1982,** *38,* 2365.

(7) (a) Aratani, T.; Yoneyoshi, Y.; Nagase, T. *Tetrahedron Lett.* **1982,** *23,* 685. (b) Aratani, T.; Yoneyoshi, Y.; Nagase, T. *Tetrahedron Lett.* **1977,** 2599.

(8) (a) Evans, D. A.; Woerpel, K. A.; Hinman, M. M.; Faul, M. M. *J. Am. Chem. Soc.* **1991,** *113,* 726. (b) Lowental, R. E.; Abiko, A.; Masamune, S. *Tetrahedron Lett.* **1990,** *31,* 6008.

(9) (a) Leutenegger, U.; Umbricht, G.; Fahmi, C.; von Matt, P.; Pfaltz, A. *Tetrahedron* **1992,** *48,* 2143. (b) Fritschi, H.; Leutenegger, U.; Pfaltz, A. *Helv. Chim. Acta* **1988,** *71,* 1553.

(10) Tokar, C. J.; Kettler, P. B.; Tolman, W. B. *Organometallics* **1992,** *11,* 2737.

(11) Kwart, H.; Khan, A. A. *J. Am. Chem. Soc.* **1967,** *89,* 1951.

(12) Mahy, J.-P.; Bedi, G.; Battioni, P.; Mansuy, D. *J. Chem. Soc.,* Perkin *Trans 2* **1988,** 1517.

(13) Evans, D. A.; Faul, M. M.; Bilodeau, M. T. *J. Org. Chem.* **1991,** *56,* 6744.

(14) Thompson, J. S.; Harlow, R. L.; Whitney, J. F. *J. Am. Chem. Soc.* **1983,** *105,* 3522.

(15) Alkene cyclopropanation: complex 1 (40 mg, 0.1 mmol) was dissolved in 5 mL of 1,2-dichloroethane, and 300 equiv of the olefin was added. Ethyl diazoacetate (0.95 mL, 10 mmol) was diluted in 20 mL of 1,2-dichloroethane and added slowly (16–18 h) with a syringe pump to the [Cu]–alkene mixture. Solvent and excess olefin were removed under vacuum, and the residue was purified by chromatography on an alumina column. A 5:1 hexane–EtOAc mixture was used to elute the samples. Alkyne cyclopropenation was achieved by following the same procedure but employing a 5-fold excess of the alkyne.

0276-7333/93/2312-0261$04.00/0

Table I. Alkene Cyclopropanation Catalyzed by $Tp'Cu(C_2H_4)^a$ (1)

olefin	olefin/EDA	cyclopropane[b]	yield[c] (%)	syn:anti[d]
styrene	3	**2a**	94 (75)	57:43
cis-cyclooctene	3	**2b**	96 (78)	1:99
1-hexene	3	**2c**	76 (63)	50:50
trans-stilbene	3–5		0	

[a] 1 mol % of catalyst used, relative to EDA. Reactions were performed at 25 °C.[15] [b] Products were characterized by NMR spectroscopy; data were identical with those reported in the literature.[17] [c] Determined by ^1H NMR analyses at the end of the reactions. Yields in parentheses are isolated yields after chromatographic purification. [d] Obtained by ^1H NMR integration of methylene ester resonances.

Table II. Alkyne Cyclopropenation Catalyzed by $Tp'Cu(C_2H_4)^a$ (1)

alkyne[b]	cyclopropene[c]	yield[d] (%)
1-hexyne	**3a**	47 (33)
3-hexyne	**3b**	41 (30)
1-phenyl-1-propyne	**3c**	64 (51)

[a] 1 mol % of catalyst used, relative to EDA. Reactions were performed at 25 °C.[15] [b] Alkynes were distilled before use. A 5-fold excess relative to EDA was used. [c] Products were characterized by NMR spectroscopy; data were identical with those reported in the literature.[18] [d] Determined by ^1H NMR analyses at the end of the reactions. Yields in parentheses are isolated yields after chromatographic purification.

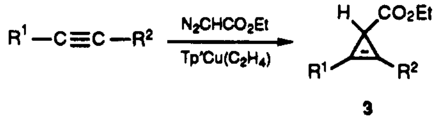
Table III. Alkene Aziridination Catalyzed by $Tp'Cu(C_2H_4)^a$ (1)

olefin	aziridine[b]	yield[c] (%)
styrene	**4a**	90
cis-cyclooctene	**4b**	75
1-hexene	**4c**	40

[a] 5 mol % of catalyst used, relative to PhI=NTs. A 10-fold excess of the olefin was employed. Reactions were performed at 25 °C.[20] [b] Products were characterized by NMR spectroscopy; data were identical with those reported in the literature.[12] [c] Isolated yields after crystallization.

results obtained with several olefins. Styrene and cyclooctene display similar reactivities, with yields higher than 90% when only a 3-fold excess of olefin is employed. Under identical conditions, 1-hexene gives ethyl 2-*n*-butylcyclopropanecarboxylate (**2c**) in 76% yield. The ratio of diastereomers formed was found to be close to 1:1 except for cyclooctene, which preferentially affords the anti isomer. Low-temperature ^1H NMR experiments have shown that these reactions do not take place below 0 °C. Above 0 °C, transformation of reagents into products is relatively fast. When styrene is used as the alkene, $Tp'Cu(CH_2{=}CHPh)$,[16] a simple styrene adduct, has been identified as the catalyst resting state. It is the copper species observed during and after the reaction. *trans*-Stilbene does not react under transfer conditions; diethyl fumarate and maleate are obtained as the sole products. A sterically hindered approach of the trans-disubstituted alkene to the presumed copper carbene complex intermediate may account for the lack of reactivity.

In a similar fashion, alkynes react at room temperature with EDA in the presence of catalytic amounts of $Tp'Cu(C_2H_4)$ (eq 2) to afford the corresponding cyclopropenes in moderate yields (Table II). To date, several copper systems have been reported to catalyze these transformations.[1,3] However, high temperatures are usually required (90–140 °C), and yields vary significantly in the case of disubstituted (30–75%) and terminal (<20%) alkynes. Preliminary results suggest that our system substantially improves conditions and yields. Both internal and terminal alkynes are converted into cyclopropenes at room temperature in moderate yields. 1-Hexyne was converted to cyclopropene **3a** in 47% yield. The same degree of conversion is observed when 3-hexyne or 1-phenyl-1-propyne is the alkyne (Table II). The observed efficiency of $Tp'Cu(C_2H_4)$ is better than that of other copper species and nearly comparable to that reported for $Rh_2(OAc)_4$,[1] a well-known catalyst for such transformations.

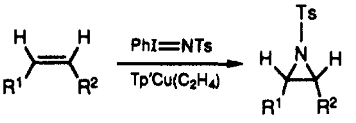


(2)

3

3a: $R^1 = H$, $R^2 = {}^nBu$
b: $R^1 = Et$, $R^2 = Et$
c: $R^1 = Me$, $R^2 = Ph$

The catalytic capabilities of $Tp'Cu(C_2H_4)$ are not restricted to carbene transfer processes. Alkenes and ((*p*-tolylsulfonyl)imino)phenyliodinane, PhI=NTs,[19] produce aziridines (eq 3) in high yields (Table III) when **1** is present in the reaction mixture.[20] These reactions require anhydrous conditions; otherwise, $TsNH_2$ is formed and aziridine yields are diminished. Styrene quantitatively gives 2-phenyl-1-tosylaziridine (**4a**), while cyclooctene and 1-hexene form the corresponding aziridines **4b** and **4c** in lower yields.



(3)

4

4a: $R^1 = H$, $R^2 = Ph$
b: $R^1 = R^2 = -(CH_2)_6-$
c: $R^1 = H$, $R^2 = {}^nBu$

In summary, $Tp'Cu(C_2H_4)$ is an efficient Cu(I) catalyst which functions under mild conditions to transfer $HCCO_2Et$ to alkenes and alkynes and $NSO_2C_6H_4CH_3$ to alkenes to form cyclopropanes, cyclopropenes, and aziridines. Mechanistic studies of this structurally well-defined Cu(I) system are in progress.

Acknowledgment. We are grateful to the National Institutes of Health (Grant No. GM28938) and the Department of Energy (Contract No. DE-FG05-85ER13430) for financial support. P.J.P. also thanks the Ministerio de Educación y Ciencia (Spain) for a research studentship.

OM920700F

---

(16) Selected ^1H NMR data for $Tp'Cu(CH_2{=}CHPh)$: δ 4.58 (dd, 1 H, *H*HC=CHPh), 4.06 (dd, 1 H, H*H*C=CHPh), 3.10 (dd, 1 H, $H_2C{=}C$*H*Ph), 2.43 (s, 9 H, 3 C*H*$_3$), 2.09 (s, 9 H, 3 C*H*$_3$).

(17) Ancieux, A. J.; Hubert, A. J.; Noels, A. F.; Petiniot, N.; Teyssié, P. *J. Org. Chem.* **1980**, *45*, 695 and references cited therein.

(18) (a) Donaldson, W. A.; Hughes, R. P. *J. Am. Chem. Soc.* **1982**, *104*, 4846. (b) Petiniot, N.; Ancieux, A. J.; Noels, A. F.; Hubert, A. J.; Teyssié, P. *Tetrahedron Lett.* **1978**, *14*, 1239.

(19) Yamada, Y.; Yamamoto, T.; Okawara, M. *Chem. Lett.* **1975**, 361.

(20) Aziridination reactions: complex 1 (20 mg, 0.05 mmol) was placed in a Schlenk flask along with 40 mL of dry, freshly distilled CH_2Cl_2 and molecular sieves. Olefin (200 equiv) was added via syringe, and the mixture was stirred for 15 min. PhI=NTs was then added portionwise over 1 h. After 2 h the reaction mixture was centrifuged and volatiles were removed under vacuum. Extracting the residue with ethanol and cooling to −20 °C led to the isolation of **4a–c** as off-white crystalline solids.