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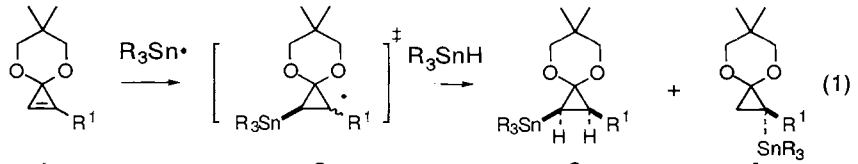
Hydrostannation of Cyclopropene. Strain-Driven Radical Addition Reaction

Shigeru YAMAGO, Satoshi EJIRI,† and Eiichi NAKAMURA*
Department of Chemistry, Tokyo Institute of Technology, Meguro, Tokyo 152

Hydrostannation of substituted cyclopropenone acetals with trialkyltin hydride takes place smoothly under radical conditions to afford a variety of 2-alkyl-3-stannylcyclopropanone acetals in high yield. Comparison of the cyclopropene with acetylenes with the aid of inter- and intramolecular competitive experiments revealed the kinetically controlled nature of the reaction of the cyclopropene reaction.

Tremendous efforts have been expended in the past decade for the controlled addition of organic radicals to a variety of X-Y multiple bond. Owing to the extensive research worldwide, the repertoire of the radical acceptor now appears to covers most of the X-Y structure.[1] We report here our preliminary results of the study on the radical-accepting ability of cyclopropene, which is an important class of radical acceptors yet to be included in this repertoire. We found that the strained C=C bond in the cyclopropene accepts a tin radical as efficiently as an acetylene, and far more smoothly than common olefins.



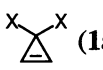
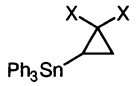
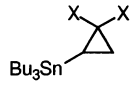
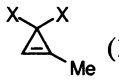
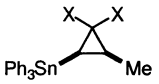
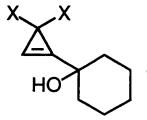
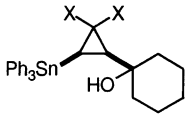
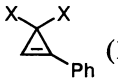
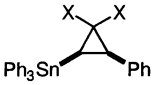
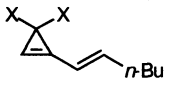
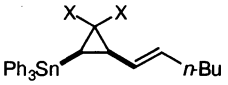
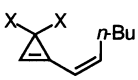
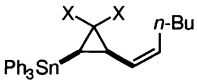
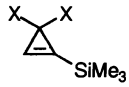
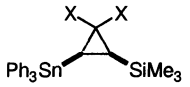
1 **2** **3** **4**

For this exploratory study on the strain-driven reaction, we have chosen the simplest bimolecular reaction of an organotin hydride and a cyclopropenone acetal[2] (CPA) (eq 1). The hydrostannation of a C–C multiple bond proceeds in two steps:[3] a tin radical adds reversibly to the C–C bond and the incipient β-stannyl alkyl radical (e.g. **2**) reacts irreversibly with a tin hydride reagent to give the hydrostannation product and a tin radical. The latter further carries the radical chain. The hydrostannation reaction, hence, is generally a composite result of the two crucial steps, radical addition and hydride abstraction. In the cyclopropene reaction, the strain energy is expected to make the first step irreversible, and, thus, to improve the efficiency of the overall reaction.

Whereas the tin radical addition is very slow for unactivated olefins,[4] the addition to CPA proceeded rapidly in high yield. When a mixture of **1** and Ph_3SnH (1.1 equiv) was heated in toluene for 1.1 h at 60 °C in the presence of AIBN, 2-(triphenylstannyl)cyclopropanone acetal **3a** (R^1 =H) was obtained in 99% isolated yield (Table 1, entry 1). Initiation of the chain reaction with 10 mol% Bu_3B[5] allowed the reaction to proceed at room temperature, and ultrasound initiation[6] of an ice-cooled mixture also took place in high yield.

† Deceased.

Table 1. Hydrostannation of Cyclopropenone Acetal [a]

entry	cyclopropene	R	method[b]	temp °C	time h	major product	%yield[c]	(3:4)[d]
1	 (1a)	Ph	A	60	1.1		99	–
			B	room temp	1.4		100	
			C	7	5		83	
2	1a	*n*-Bu	B	room temp	2		64	–
3	 (1b)	Ph	A	60	1.1		90	(7:3)
4	 (1c)	Ph	B	0	0.5		99	(>99[e]):1)
5	 (1d)	Ph	B	room temp	0.67		96	(>98[e]):2)
6	 (1e)	Ph	B	room temp	5		68	(>98:2)
7	 (1f)	Ph	B	room temp	2.5		92	(>98[e]):2)
8	 (1g)	Ph	B	room temp	0.25		100	(>99[e]):1)

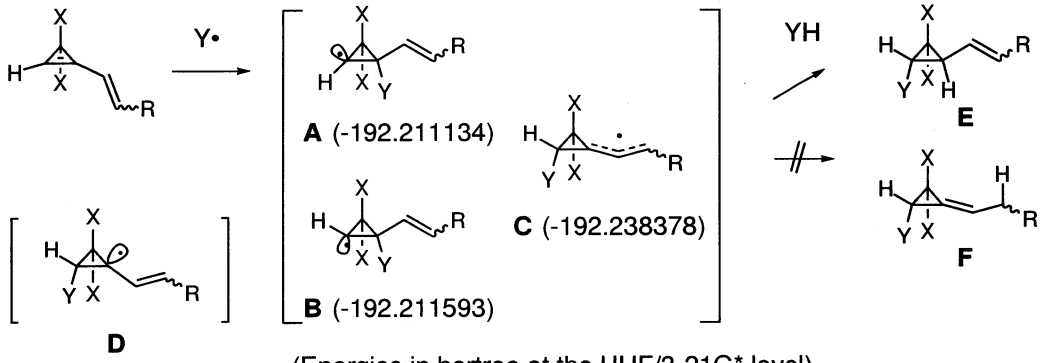
a) A cyclopropenone acetal and R_3SnH (1.1 equiv) reacted in toluene under nitrogen in the presence of a radical initiator or under ultrasound irradiation. X, X = $OCH_2C(CH_3)_2CH_2O$. b) A: AIBN (10 mol%) was used. B: *n*-Bu_3B or Et_3B (10 mol%) was used. C: Ultrasound irradiation. c) Isolated yield. d) Determined by ^1H NMR and/or isolation of the products. e) The product consisted of a 87:13, 85:15, 88:12, and 95:5 mixture of *cis* and *trans* isomer for entries 4, 5, 7, 8, and 9, respectively.

Hydrostannation with Bu_3SnH was slower but also proceeded in a reasonable yield (entry 2).[7]

With substituted CPAs, there arises a regiochemical issue. We have studied substrates **1b** to **1g**, bearing substituents of various steric and electronic characters (Table 1, entries 3-8). In all these cases, the addition took place regioselectively to give vicinally substituted products, and, except the methylcyclopropene **1b** which was only 70% selective, the regioselectivity was extremely high. The stereochemistry of all of the vicinal products was cis, and the cis/trans ratio (85:15–95:5) was relatively insensitive to the substituent on the CPA.

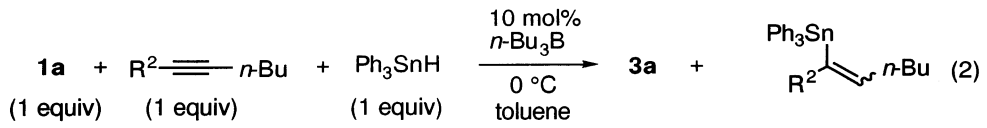
It is notable that the reaction of *E* and *Z*-olefinic isomers of vinylcyclopropenes in entries 6 and 7 proceeded with retention of both the location and the geometry of the olefin bond. Though the addition of $Ph_3Sn\bullet$ to the vinyl CPA (X = OR) would generate four isomeric radicals **A**–**D** (Y = Ph_3Sn), the observed reaction took a singe pathway, through **C**, which abstracts hydride from Ph_3SnH exclusively on the cyclopropyl carbon. Thermodynamic analysis with the aid of the theoretical calculations provided a rationale for this selectivity. Several key data were obtained by the ab initio molecular orbital calculations[8] with the 3-

21G* basis set for simple model species (X = Y = R = H). The cyclopropyl radicals **A** and **B** were found to be discrete species and both are much less stable than the conjugated isomer **C** (by 17.1 and 16.8 kcal/mol, respectively). Second, there was found only the fully conjugated radial **C**, and the radical **D** was not found to be a minimum. The allylic radical **C** is strained and expected to react rapidly with a tin hydride reagent without loosing stereochemical integrity. Finally, the strain energy **C** is best liberated by the formation of **E** rather than by that of **F**, which is less stable by 8.95 kcal/mol.



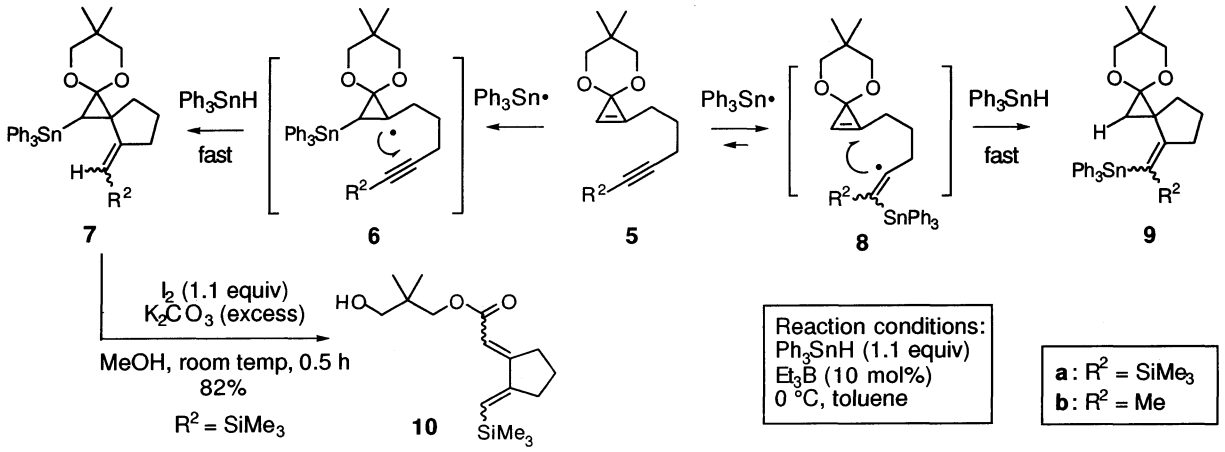
(Energies in hartree at the UHF/3-21G* level)

The above data demonstrated that CPA is an excellent radical acceptor. In order to examine the origin of such high reactivity, we compared CPA with acetylene by using inter- and intramolecular competition probes. In the intermolecular competition, Ph_3SnH reacted with an equimolar mixture of **1a** and 1-hexyne in the presence of Et_3B at 0 °C, and 73% of the hydrostannation product came from the CPA and 24% from 1-hexyne (eq 2). In a competition using more hindered acetylene, 1-trimethylsilyl-1-hexyne, all product was due to the CPA and the acetylene was recovered. In a separate run, this internal acetylene by itself was found to be totally inactive to Ph_3SnH. Thus, CPA was found to be a much better radical acceptor than an internal acetylene.



Intramolecular competition using the CPAs **5a** and **5b** bearing an internal acetylenic bond, however, revealed another aspect of relative reactivity of CPA and internal acetylenes. In this competition, not only the strain-driven radical addition to CPA (forming **6**) but also the addition to the acetylene moiety (forming **8**) would become effectively irreversible because of rapid intramolecular trapping of the incipient vinyl radical **8** by the internal cyclopropene. The competition experiment hence should give us an opportunity to compare the kinetic reactivity of CPA and acetylene. Unlike in the intramolecular probe, they were found to be equally reactive in a kinetic sense. Thus, the reaction of **5a** with Ph_3SnH gave a mixture of stannyl cyclopropane **7a** and vinyltin **9a** in 55% and 45% isolated yield, respectively.[9] Similarly, the acetylenic CPA **5b** also gave a similar mixture of isomeric cyclization products (**7b** in 49% and **9b** in 24%).[10] Therefore, it is clear that the apparently low reactivity of the internal acetylene in the intermolecular probe is due to unfavorable thermodynamics at the initial radical addition to form the corresponding vinyl radical. As has been discussed in the theoretical analysis of strain-driven addition of nucleophiles to cyclopropene,[11] it is not surprising that

the radical addition has not gained too much kinetically from the ring strain, since such a highly exothermic reaction would go through a very early transition state, wherein only a part of the ring strain is released. It may be interesting from synthetic view that treatment of the cyclization product **7a** with iodine in methanol cleaves the cyclopropane ring to give the diene **10** in 82% yield as a 1:1 mixture of two geometrical isomers.



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6) E. Nakamura, D. Machii, and T. Inubushi,. *J. Am. Chem. Soc.* **111**, 6849 (1989).
7) Typical reaction procedure: tributylborane (84 mg, 0.46 mmol) was added to a solution of **1a** (0.64 g, 4.6 mmol) and triphenylstanane (1.93 g, 5.5 mmol) in 37 mL of toluene under nitrogen at room temperature. After stirring for 1 h, water was added and extractive work-up followed by purification on silica gel afforded **3a** in quantitative yield (2.26 g, 4.6 mmol).
8) Calculations with a SPARTAN ver 2.0 package: Wave function, Inc., Irvine, CA, (1991).
9) The adducts **7a** and **9a** consisted of a 95:5 and 2:1 mixture of two isomers, respectively.
10) The adducts **7b** and **9b** consisted of a 64:36 and 7:3 mixture of two isomers, respectively.
11) E. Nakamura, M. Nakamura, Y. Miyachi, N. Koga, and K. Morokuma, *J. Am. Chem. Soc.*, **115**, 99 (1993).

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