



Initiating radical cyclizations by H• transfer from transition metals

John Hartung, Mary E. Pulling, Deborah M. Smith[†], David X. Yang, Jack R. Norton^{*}

Department of Chemistry, Columbia University, 3000 Broadway, New York, NY 10027, USA

ARTICLE INFO

Article history:

Received 2 October 2008

Accepted 10 October 2008

Available online 17 October 2008

Keywords:

Radical cyclization

Hydrogen atom transfer

Transition-metal hydrides

Acrylates

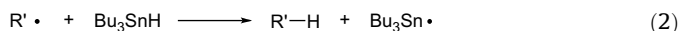
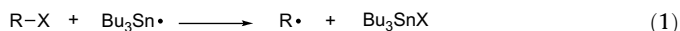
ABSTRACT

CpCr(CO)₃H and HV(CO)₄(P–P) (where P–P is a chelating diphosphine) can be used to initiate radical cyclizations by transferring H• to activated terminal olefins. CpCr(CO)₃H can catalyze reductive cyclizations, with H₂ as the ultimate reductant. Appropriate substrates can be assembled by the Morita–Baylis–Hillman reaction of methyl acrylate with an aldehyde. Six- as well as five-membered rings can be formed, and a tandem cyclization to decalin can be effected.

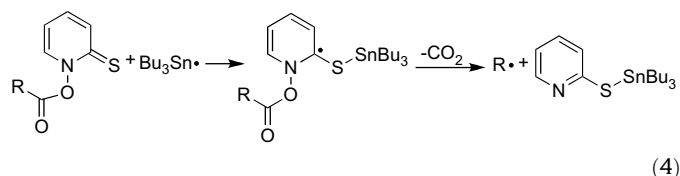
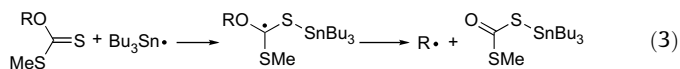
© 2008 Elsevier Ltd. All rights reserved.

1. Introduction

Methods involving carbon-centered radicals are extensively used in synthesis, particularly in cyclization reactions. Such radicals can be generated in many ways, the most common being the abstraction of X• by an organotin radical (Eq. 1), where X is Br, I, occasionally Cl, or PhSe or PhS.¹ The radical R•, often after cyclization or rearrangement, then abstracts H• from a tin hydride (typically Bu₃SnH), regenerating the tin radical (Eq. 2) and continuing the chain.



Related methods begin with the addition of a tin radical to the C=S double bond in a xanthate (Eq. 3) or thiohydroxamate (Eq. 4) ester.^{1,2} The resulting intermediates then give R• by β-scission and decarboxylation (Eq. 4).



Such methods are necessarily stoichiometric both in tin and in another heavy element (Br, I, Se, S). In the laboratory, special care is required to handle trialkyltin hydrides and the waste they generate, and standard purification techniques often leave toxic levels of tin compounds in the product.³ The industrial application of these methods has been hindered by the need to remove such tin-containing byproducts. In order to ameliorate this problem, methods catalytic in tin have been developed,^{4–6} and tin hydride reagents modified to make their removal easier.^{7–13} However, the need for alternatives to tin remains as evidenced by reviews such as ‘Flight from the Tyranny of Tin’.^{14–17} Substitutes such as *N*-ethylpiperidinium hypophosphite,¹⁸ (Me₃Si)₃SiH,¹⁹ Bu₃GeH,²⁰ HGaCl₂,²¹ and HInCl₂²² contain a bond to hydrogen stronger than the 78 kcal/mol one in Bu₃SnH²³ and are therefore likely to be less reactive at H• transfer.

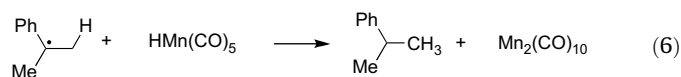
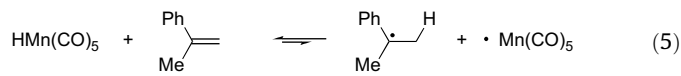
Bonds to hydrogen weaker than Sn–H are common in transition-metal hydrides. Although an Os–H bond >82 kcal/mol has been reported,²⁴ most M–H bonds lie between 60 and 65 kcal/mol.²⁵ We have found V–H bonds (see below) as weak as 55 kcal/mol.²⁶ These weak bonds enable transition-metal hydrides to generate radicals in ways not available to tin hydrides. In 1977 Sweany and Halpern concluded, after observing CIDNP and an inverse H/D isotope effect, that the hydrogenation of α-methylstyrene by HMn(CO)₅ (Eqs. 5 and 6) begins with the reversible transfer of H• from Mn to the olefin.²⁷ (They presumed the new C–H bond to have a frequency of

^{*} Corresponding author. Tel.: +1 212 854 7644; fax: +1 212 854 7660.

E-mail address: jrn11@columbia.edu (J.R. Norton).

[†] Present address: Johnson & Johnson PRD, 3210 Merryfield Row, San Diego, CA 92121, USA.

$\sim 3000\text{ cm}^{-1}$, and implied that the inverse isotope effect arose from the equilibrium in Eq. 5. However, such C–H bonds are weakened by an adjacent radical center,²⁸ and ΔH for Eq. 5 is *endothermic*, +8 to 10 kcal/mol,^{29,30} which raises the possibility³¹ that the observed inverse effect has a *kinetic* origin.³²



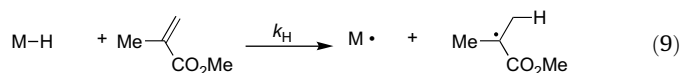
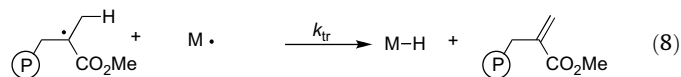
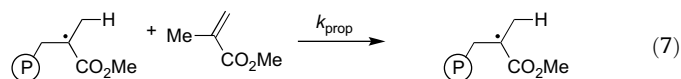
Some years ago we showed that $\text{CpCr(CO)}_3\text{H}$ (**1**) and related Cr hydrides could serve as $\text{H}\cdot$ donors to methyl methacrylate and styrene.^{29,30} However, these Cr–H bonds are 62–64 kcal/mol and their $\text{H}\cdot$ transfer reactions were not fast. We considered where we might find weaker M–H bonds, and noted (1) the unusually efficient transfer of $\text{H}\cdot$ to a carbon radical from an anionic vanadium hydride,³³ (2) a number of papers in which vanadium hydrides appeared to transfer $\text{H}\cdot$ onto various dienes,^{34,35} and (3) a calculation on the hypothetical VH_5 that gave it the weakest M–H bond of any of the hydride complexes considered.³⁶ We therefore prepared a series of vanadium hydrides $\text{HV(CO)}_4(\text{P-P})$ ($\text{P-P}=\text{Ph}_2\text{P}(\text{CH}_2)_n\text{PPh}_2$, with $n=1$ (dppm), $n=2$ (dppe), $n=3$ (dppp), and $n=4$ (dppb)) (**2a–d**),^{37,38} determined the strength of their V–H bonds, and found that these bonds are indeed weak (Table 1).³⁹

Table 1
Bond dissociation energies of some chromium and vanadium hydrides

M–H	M–H BDE (kcal/mol)
$(\eta^5\text{-C}_5\text{H}_5)\text{Cr(CO)}_3\text{H}$ (1)	62.2
$\text{HV(CO)}_4(\text{dppm})$ (2a)	57.9
$\text{HV(CO)}_4(\text{dppe})$ (2b)	57.5
$\text{HV(CO)}_4(\text{dppp})$ (2c)	56.0
$\text{HV(CO)}_4(\text{dppb})$ (2d)	54.9

The V–H bonds in **2a–d** transfer $\text{H}\cdot$ more rapidly than does the Cr–H bond in **1**, although the increase in rate is not as large as one would expect from the decrease in M–H bond strength. $\text{HV(CO)}_4(\text{dppe})$ (**2b**) transfers $\text{H}\cdot$ to styrene about 10 times more rapidly than does **1**.³⁹ Presumably, the steric bulk of the chelating ligand undermines the effect of the weaker bond.

Such $\text{H}\cdot$ transfer reactions are familiar as part of the catalytic cycle for chain transfer during radical polymerizations (Eq. 7). In the first step of that cycle, Eq. 8, $\text{H}\cdot$ is removed from the chain-carrying radical; its transfer to fresh monomer (Eq. 9) begins a new chain.⁴⁰ The competition between Eq. 8 and propagation (Eq. 7) reduces the chain length and molecular weight of the polymer.



Metalloradicals $\text{M}\cdot$ have proven to be effective catalysts for chain transfer. The original catalysts were macrocyclic cobalt(II) complexes,⁴⁰ but their hydrides are unobservable during the catalytic cycle, apparently because they are so efficient in transferring $\text{H}\cdot$ back to monomer (Eq. 9). We have found that Cr metalloradicals are almost as effective while offering the advantage that their hydrides are stable enough to be observed during catalysis. For the polymerization of methyl methacrylate, $(\text{C}_5\text{Ph}_5)\text{Cr(CO)}_3\cdot$ is a good chain transfer catalyst, $\text{CpCr(CO)}_3\cdot$ (in equilibrium with its dimer) is a much better one,⁴¹ and the vanadium metalloradical $\text{V(CO)}_4(\text{dppe})\cdot$ shows respectable activity.⁴² This effectiveness implies that the corresponding hydrides ($(\text{C}_5\text{Ph}_5)\text{Cr(CO)}_3\text{H}$, **1**, and **2b**) are efficient in transferring $\text{H}\cdot$ back to methyl methacrylate.

The effectiveness with which M–H bond strengths can control rates of $\text{H}\cdot$ transfer is illustrated by the recent work of O'Connor and Frieze on Bergman cycloaromatizations. They found that $\text{CpW(CO)}_3\text{H}$, with an M–H bond strength of 72 kcal/mol,²⁵ does not react with an enediyne but does transfer $\text{H}\cdot$ to the diradical formed by its cyclization.⁴³

Using $\text{H}\cdot$ transfer to selectively generate radicals requires that we know the relative rates at which such transfers occur to various olefins. There has been virtually no information on the rate constants k_{H} with which different double bonds accept $\text{H}\cdot$. We have therefore examined the reactivity of $\text{CpCr(CO)}_3\text{H}$ (**1**) toward the nine olefins in Table 2, determining k_{H} from either the rate of H/D exchange or the rate of hydrogenation.²⁶

The stability of the resulting radical has a large effect on k_{H} : olefins bearing phenyl substituents (entries 1–3 and 8) accept $\text{H}\cdot$ more readily than do olefins bearing CO_2Me substituents (entries 4, 6, and 9), although the latter accept $\text{H}\cdot$ more readily than do olefins bearing methyl substituents. Additional methyl or phenyl substituents on the α carbon—which provide additional stabilization for the radical being generated—increase the rate further.

Table 2
Rate constants k_{H} for $\text{H}\cdot$ transfer from $\text{CpCr(CO)}_3\text{H}$ to various olefins at 323 K

Entry	Olefin	$k_{\text{H}} (\times 10^{-3}) (\text{M}^{-1} \text{s}^{-1})$	Relative rate
1		0.59 (2)	1
2		460 (60)	780
3		79 (3)	134
4		$\leq 3.2 \times 10^{-4}$	$\leq 5 \times 10^{-4}$
5		$\leq 1.1 \times 10^{-4}$	$\leq 2 \times 10^{-4}$
6		$(0.8\text{--}1.6) \times 10^{-2}$	≈ 0.02
7		$\leq 3.2 \times 10^{-3}$	≤ 0.005
8		15.8 (6)	27
9		14 (3)	24

Download English Version:

<https://daneshyari.com/en/article/5223583>

Download Persian Version:

<https://daneshyari.com/article/5223583>

[Daneshyari.com](https://daneshyari.com)