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Rate constants for the reaction of cumylperoxyl radicals with Bu_3SnH and $(TMS)_3SiH$

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The rate constants for the reaction of a cumylperoxyl radical with Bu_3SnH and $(TMS)_3SiH$ were determined at 72.5 °C to be 1600 and 66 M^{-1} s^{-1}, respectively, by using inhibited hydrocarbon oxidation methodologies.

In the last two decades, radical chain reactions have proven to be valuable in synthetic organic chemistry.[1a] The majority of such chain processes have been carried out by using Bu_3SnH or $(TMS)_3SiH$, which are the most widely used reagents under reduction conditions.[1] For a synthetically useful radical chain reaction the intermediates must be *disciplined*. The concept of discipline[2] in free radical reactions is strictly connected with the kinetic information of each individual step, although upon first consideration, the importance of the kinetic knowledge might be less apparent in planning a synthetic strategy.

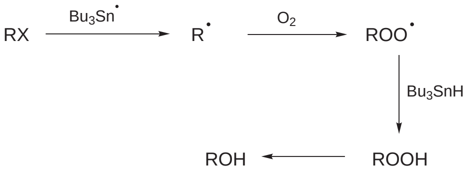
The reaction of peroxyl radicals with organic substrates is one of the most important classes of reactions in chemistry,[3] being the key step of several processes, *e.g.* autoxidation of synthetic polymers, lipid peroxidation and DNA damage. The use of alkylperoxyl radicals in synthesis is limited to a few procedures.[4,5] In one of them, the conversion of halides to alcohols has recently been approached by tin hydride reduction under aerobic conditions.[5] The reaction sequence that has been suggested is shown in Scheme 1. Examples in which the alkyl radical rearranges itself prior to the reaction with molecular oxygen are reported,[5] although in some cases the reaction is sluggish and gives undesired products.[6] Nakamura and co-workers were able to run these experiments under conditions where hydroperoxides were isolated in good yields.[7] In one case, the $(TMS)_3SiH$ mediated halide to alcohol transformation was reported to give a moderate yield.[7] In all these transformations, the reaction of a peroxyl radical with a tin or silicon hydride is crucial. Kinetic information regarding this step is not available. In their recent mechanistic studies on model DNA damage, Greenberg and co-workers[8] arbitrarily assumed the rate constants for the ROO• radical with Bu_3SnH to be 5×10^3 M^{-1} s^{-1} at 55 °C in THF. Following these considerations, the knowledge of the rate constants for the reaction of peroxyl radicals with Bu_3SnH and $(TMS)_3SiH$ turns out to be necessary for better synthetic planning as well as a reference reaction for mechanistic studies.

Herein we report the rate constants of a cumylperoxyl radical with $(TMS)_3SiH$ and Bu_3SnH which have been determined by using inhibited hydrocarbon oxidation methodologies.[9,10] In particular, two different kinetic approaches were used for the two reducing agents, depending on the presence or absence of an induction period when they are used as antioxidants. Scheme 2 shows that the initiation and propagation steps are identical for the two methods, whereas the termination steps are different.

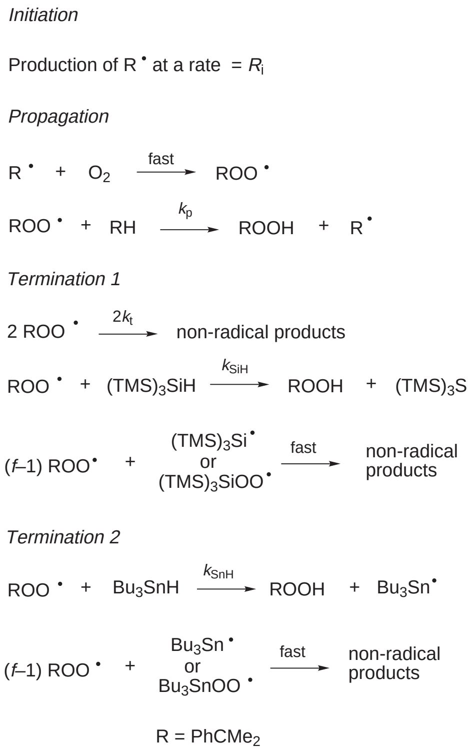
Providing that conditions can be found in which *termination 1* is applied, the rate constant for H-atom abstraction from the silane by cumylperoxyl radicals can be obtained from eqn. (1),[9]

$$\frac{(-\mathrm{d}[O_2]/\mathrm{d}t)_0}{(-\mathrm{d}[O_2]/\mathrm{d}t)} - \frac{(-\mathrm{d}[O_2]/\mathrm{d}t)}{(-\mathrm{d}[O_2]/\mathrm{d}t)_0} = \frac{fk_{\mathrm{SiH}}[(\mathrm{TMS})_3\mathrm{SiH}]_0}{(2k_t R_i)^{1/2}} \qquad (1)$$

where $(-\mathrm{d}[O_2]/\mathrm{d}t)$ and $(-\mathrm{d}[O_2]/\mathrm{d}t)_0$ represent the initial rate of oxidation of cumene with or without $(TMS)_3SiH$.‡ The stoichiometric factor *f*, which is the number of cumylperoxyl radicals trapped by each molecule of silane, is assumed to be equal to 2.§ The inhibition of thermally initiated (0.021 M of AIBN at 345.5 K) oxidation of pure cumene by $(TMS)_3SiH$ (concentration range of 1.84×10^{-4} to 6.13×10^{-4} M) is found to be the case. Fig. 1 shows that the oxidation rate of cumene decreases upon increasing the concentration of silane without an induction period. On the other hand, Fig. 1 also shows the linear regression analysis of eqn. (1), whose slope provides $2k_{\mathrm{SiH}}/(2k_t R_i)^{1/2}$ to be 7.1×10^2 M^{-1}. Since the rate of radical production[11]



Scheme 1



Scheme 2

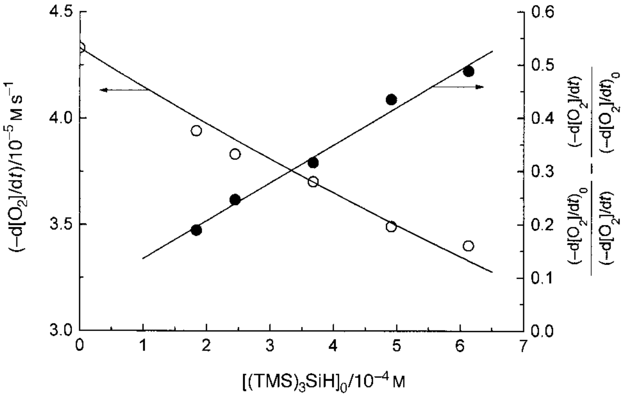


Fig. 1 Plots of (○) $-d[O_2]/dt$ and (●) $(-d[O_2]/dt)_0/(-d[O_2]/dt) - (-d[O_2]/dt)/(-d[O_2]/dt)_0$ *vs.* $[(TMS)_3SiH]$; [AIBN] = 0.021 M at 345.5 K.

and the termination for cumylperoxyl radicals[12] are $R_i = 1.09 \times 10^{-6}$ M s^{-1} and $2k_t = 3.2 \times 10^4$ M^{-1} s^{-1}, respectively, we calculated $k_{SiH} = 66.3$ M^{-1} s^{-1} at 345.5 K.

The inhibition of thermally initiated (0.0172 M of AIBN at 345.5 K) oxidations of pure cumene by Bu_3SnH (concentration range of 1.07×10^{-3} to 3.20×10^{-3} M) shows an induction period (τ). *Termination 2* in Scheme 2 describes the inhibition mechanism and the initial rate of oxidation (before exiting from the induction period), given by eqn. (2), of peroxyl radicals

$$(-d[O_2]/dt) = \frac{k_p[RH]_0 R_i}{fk_{SnH}[Bu_3SnH]_0} \qquad (2)$$

trapped by each molecule of Bu_3SnH. The use of Boozer *et al.*'s induction period method,[13] of which an example is illustrated in Fig. 2 (*i.e.* suppression of the oxygen uptake by the presence of Bu_3SnH) allows the determination of the τ values. Then the stoichiometric factor f can be obtained from $f = R_i\tau/[Bu_3SnH]_0$.[9,10] All the data are summarized in Table 1. From the slope of the linear plot between $-d[O_2]/dt$ and $1/[Bu_3SnH]_0$, the $k_p[RH]_0R_i/fk_{SnH}$ was found to be 11.6×10^{-9} s^{-1}.§ Taking $k_p = 1.3$ M^{-1} s^{-1},[12] $[RH]_0 = 7.188$ M, $R_i = 0.89 \times 10^{-6}$ M s^{-1},[11] and an average of $f = 0.46$, we calculated $k_{SnH} = 1559$ M^{-1} s^{-1} at 345.5 K.

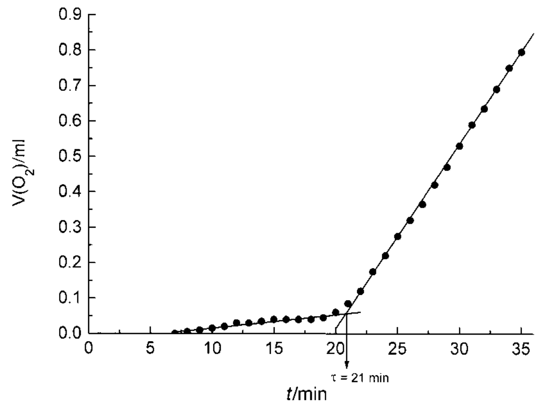


Fig. 2 Oxygen consumption during the AIBN-initiated (0.0172 M) oxidation of cumene in the presence of 2.64×10^{-3} M of Bu_3SnH at 345.5 K.

Table 1 Kinetic data for the oxidation of cumene in the presence of Bu_3SnH[a]

$(d[O_2]/dt)^b$/M s^{-1}	$[Bu_3SnH]_0$/M	v	τ/min	f
10.94×10^{-6}	1.07×10^{-3}	11.8	10	0.52
7.01×10^{-6}	1.64×10^{-3}	7.5	15	0.51
3.15×10^{-6}	2.64×10^{-3}	3.4	21	0.44
4.67×10^{-6}	3.20×10^{-3}	5.0	20	0.35

[a] [AIBN] = 0.0172 M, $R_i = 0.89 \times 10^{-6}$ M s^{-1} at 345.5 K. [b] $d[O_2]/dt = (d[O_2]/dt)_{exp} - R_i$.

In summary, the rate constants of 66 and 1600 M^{-1} s^{-1} at 345.5 K were obtained for the reaction of cumylperoxyl radicals with $(TMS)_3SiH$ and Bu_3SnH, respectively. Therefore, the alkylperoxyl radicals abstract a hydrogen atom from the tin hydride 24 times faster than from the silane. $(TMS)_3SiH$ is a notably less reactive hydrogen donor than Bu_3SnH, mainly due to the *ca.* 5 kcal mol^{-1} difference in bond dissociation energies.[14] For comparison, primary alkyl radicals and acyl radicals abstract hydrogen from the silane five and 16 times slower, respectively, than from the tin hydride at the same temperature and in much faster processes.[14]

Notes and references

† This relation can be used when the initial oxidation rate and the initiation rate remain essentially constant under the experimental conditions.

‡ This is possible if the reactions in *termination 1* dominate the systems and if the products of these reactions are not active towards initiation.

§ Since the chain length of oxidation [*i.e.* $v = (-d[O_2]/dt)_{exp}/R_i$] is less than 12, the initial rate of oxidation is corrected for oxygen absorption by the initiator, and nitrogen evolution from the initiator, *i.e.* $-d[O_2]/dt = (-d[O_2]/dt)_{exp} - R_i$, where the $(-d[O_2]/dt)_{exp}$ is the experimental initial rate of cumene oxidation.

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