Communication

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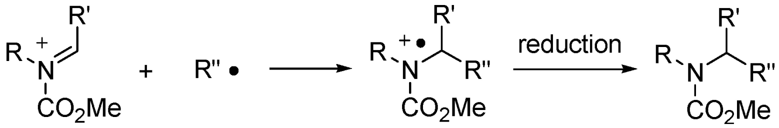

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Radical Addition to “Cation Pool”. Reverse Process of Radical Cation Fragmentation

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The removal of an electron from an organic molecule leads to the formation of a radical cation, which undergoes a variety of follow-up reactions.[1] Particularly noteworthy reaction patterns include fragmentation to give either a carbocation or a neutral carbon radical as shown in Scheme 1. Such an oxidative fragmentation serves as a key process in electrochemical,[2] photochemical,[3] and chemical[4] electron transfer-driven reactions.

Although extensive mechanistic studies have been carried out for radical cation fragmentation reactions,[5] little information is available for the reverse process: the reaction of a radical and a cation to form a radical cation.[6] We have recently developed the “cation pool” method,[7] which involves the irreversible generation and accumulation of highly reactive carbocations in the absence of nucleophiles. We envisioned that the addition of a radical to a “cation pool” would lead to the formation of the corresponding radical cation (Scheme 2). Herein, we report the results of this study.

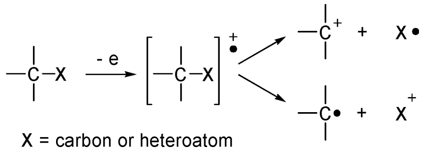
N-Acyliminium ion **2** was generated from *N*-methoxycarbonyl-2-trimethylsilylpyrrolidine **1** by low-temperature electrochemical oxidation and was accumulated in a solution (cation pool) (Scheme 3). ^{1}H and ^{13}C NMR spectra indicated the formation of **2** as an ionic species.

With a pool of *N*-acyliminium ion **2** in hand, we set out to examine whether an alkyl radical adds to **2**. After many trials to generate an alkyl radical under various conditions, we found that heptyl iodide reacted with **2** in the presence of hexabutyldistannane to give the corresponding coupling product **3** in 77% yield as shown in Scheme 4.

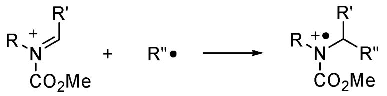
The reaction is generally applicable to various organic halides as depicted in Table 1. Primary and secondary alkyl iodides reacted with **2** to give the corresponding coupling products. The reaction also works well for other cyclic and acyclic *N*-acyliminium ions. The slow addition of the distannane was sometimes quite effective for the improvement of the yield of the addition product.

The reaction with cyclopropylmethyl iodide **4** is interesting (Scheme 5). The product having the cyclopropyl ring (**5**) was obtained together with the ring-opened product (**6**). The formation of the latter product indicated the involvement of cyclopropylmethyl radical, which isomerized to ring-opened butenyl radical.[8] Formation of the product containing cyclopropyl ring indicated that the rate of radical addition to *N*-acyliminium ion **2** is comparable to that of ring opening.[9] It is also noteworthy that the product ratio depends on the concentration of **2**. At lower concentration of **2**, the relative rate of the isomerization compared to the addition increases, and therefore, the amount of **6** increased at the expense of **5**.[10]

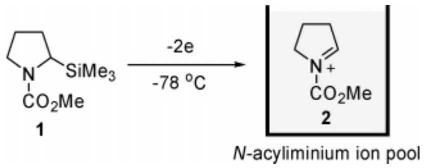
Scheme 1



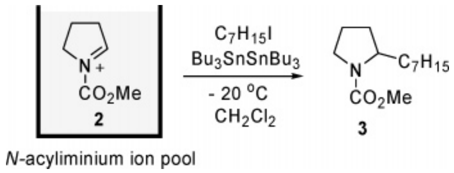
Scheme 2



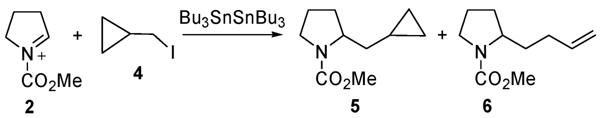
Scheme 3



Scheme 4

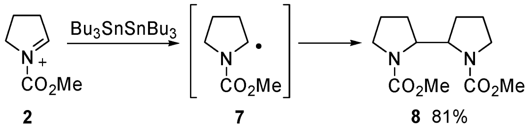


Scheme 5



concentration of **2**	**5** : **6**
0.05 M	73 : 27
0.025 M	66 : 34
0.01 M	56 : 44

Scheme 6



It is interesting to note that the present reaction does not require a radical initiator. Photo irradiation did not affect the reaction. Although the addition of a catalytic amount of 2,2,6,6-tetramethyl-1-piperidinyloxyl (TEMPO) (0.1 equiv) as a radical inhibitor did not affect the yield of **3**, the addition of a stoichiometric amount TEMPO (1.0 equiv) decreased the yield significantly (8%). These results indicate that the radical initiation process took place spontaneously in situ. It is also noteworthy that **2** reacted with hexabutyldistannane at −20 °C in the absence of an alkyl halide to give the dimeric product **8** presumably via one-electron transfer to form radical **7** (Scheme 6).[11,12]

The nature of the initiation step is not clear, and more data should be accumulated before elucidating the detailed mechanistic feature

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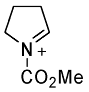
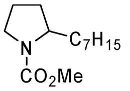
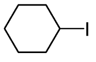
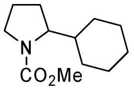
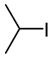
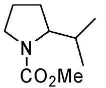
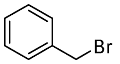
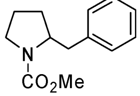
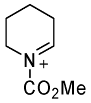
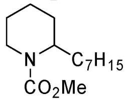
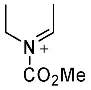
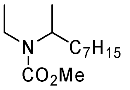
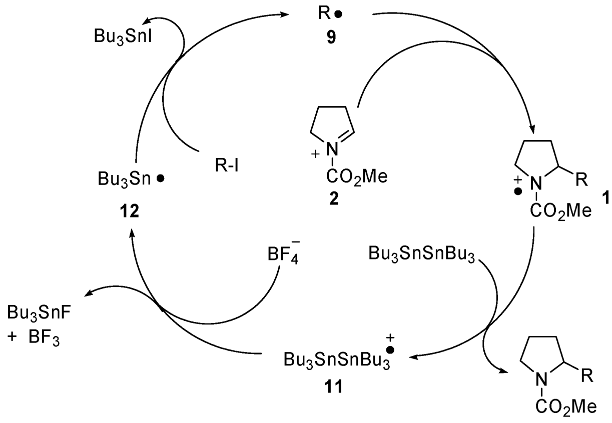
Table 1. Reactions of Organic Halides with *N*-Acyliminium Ion Pools in the Presence of Hexabutyldistannane[a]

cation pool	organic halide	product	% yield
	$C_7H_{15}I$		77 86[b]
	$C_7H_{15}Br$		20 39[b]
			60 74[b]
			43 73[b]
			69 77[b]
	$C_7H_{15}I$		35[b]
	$C_7H_{15}I$		31 57[b]

[a] Reactions were usually carried out with **2** (0.25 mmol) in 0.3 M Bu_4NBF_4/CH_2Cl_2 (5.0 mL) and an organic halide (5 equiv) and hexabutyldistannane (1.5 equiv) at −20 °C for 1 h. [b] Slow addition of hexabutyldistannane.

Scheme 7



of the present reaction, but a mechanism shown in Scheme 7 seems to be reasonable at present. In the first step, alkyl radical **9** adds to *N*-acyliminium ion **2** to generate radical cation **10**, which undergoes the electron-transfer reaction with hexabutyldistannane to give the final product. DFT calculations[13] indicate that the reduction of radical cation of carbamate to give the corresponding neutral compound (product) is thermodynamically more favorable than the reduction of *N*-acyliminium ion to radical. The radical cation of hexabutyldistannane **11** thus produced collapses to regenerate tributylstannyl radical **12**, which abstracts iodine atom from an alkyl iodide to generate alkyl radical **9**.

In conclusion, the present observations offer a striking example of the addition of a radical to a cation to form a radical cation, and they shed light on a new aspect of the chemistry of radical cations. It is also noteworthy that the present reaction opens a new possibility for radical-cation crossover[14]-mediated carbon−carbon bond formation. Further work aimed at elucidation of the detailed mechanism and the applications to the synthesis of various nitrogen containing compounds is currently in progress.

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Supporting Information Available: Experimental procedures and analytical and spectroscopic data of compounds (PDF). This material is available free of charge via the Internet at http://pubs.acs.org.

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