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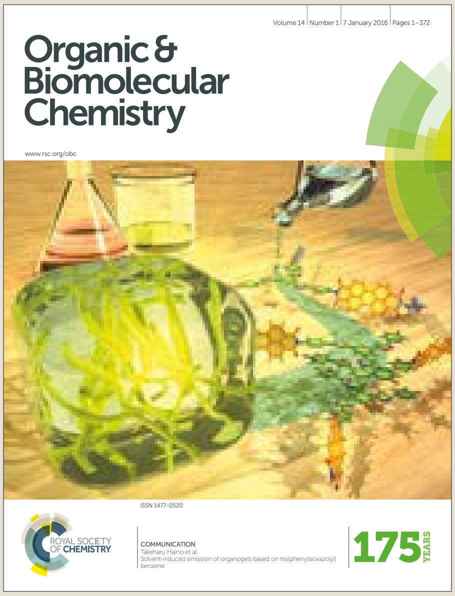

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COMMUNICATION

Carbenium ion formation by fragmentation of electrochemically generated oxonium ions

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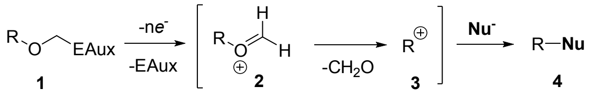
Anna Lielpetere,[a] and Aigars Jirgensons*[a]

Fragmentation of electrochemically generated oxonium ions can be exploited to form carbenium ions at low oxidation potential in the presence of a nuclephile. The application of this concept is demonstrated for allylation of carbenium ions generated by anodic oxidation of stannylmethylethers.

Electrochemical substrate activation is based on its red-ox potential enabling selective organic transformations with the electric current as the principal reactant.[1,-,6] A well-known example is anodic oxidation for the generation of carbenium ions in near-neutral conditions and avoiding the use of stoichiometric oxidants.[5,6] However, only a limited number of nucleophiles are compatible with the oxidation potential required for the substrate activation. To expand the nucleophile scope, the Yoshida group has developed electrochemical cation pool methodology where the ions are accumulated at low temperatures followed by addition of the nucleophile.[3,5,6-10] Less stable carbenium ions could be generated in the presence of sulfilimine additive leading to stabilized yet very reactive electrophilic intermediates which are acquired at low temperatures.[11] Even though the cation pool methodology is a powerful approach, it requires a divided cell set-up, and a large amount of expensive trifluorosulfonic acid for the cathode reaction.

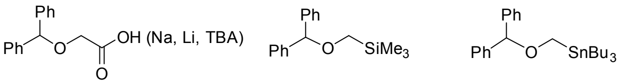
Single cell electrolysis is more attractive due to the simplicity of the experiments, however, in this case, the carbenium ions should be generated in the presence of the nucleophile. This is feasible only if the oxidation potential of the substrate is lower than that of the nucleophile, which constitutes the major challenge for the application of single cell conditions.

Oxonium ions can be produced at a relatively low potential by oxidative decarboxylation of oxyacetic acid[12,13] (non-Kolbe oxidation) or by cleavage of silylmethyl[14,15] and stannylmethyl[16,17] ethers. We hypothesised that these substructures could be exploited as electroauxilaries (EAux) in substrate **1** to produce carbenium ion **3** by fragmentation of oxonium ion **2** (Scheme 1). To ensure the reaction with the more reactive carbenium ion **3**, the nucleophile reactivity should match the fragmentation rate of oxonium ion **2** which mainly depends on the stability of carbenium ion **3**.



Scheme 1. Generation and fragmentation of oxonium ions to carbenium ions

Model substrates **1a-c** bearing oxycarbonylmethyl, trimethylsilyl-methyl and tributylstannylmethyl EAux groups were prepared from benzhydrol. The oxidation potential of the compounds was determined, revealing that tributylstannylmethyl ether is the most susceptible to electrochemical activation (Figure 1).



1a, $E^{ox} > 2$ V **1b**, $E^{ox} = 2.5$ V **1c**, $E^{ox} = 1.7$ V

Figure 1. Electroauxiliaries for the oxonium ion **2** generation (Electrochemical oxidation potentials determined by cyclic voltammetry: 0.1 M $TBABF_4$/MeCN, working electrode – glassy carbon, counter electrode – Pt wire, reference electrode – Ag/Ag^+ (potentials given *vs* NHE))

This substrate, **1c**, was subjected to electrochemical oxidation at constant current conditions in the presence of methanol which served both as a nucleophile and a proton donor for the cathode reaction (Table 1). In methanol as the reaction solvent, both carbenium ion and oxonium ion methoxylation products **5** and **6** formed in equal amounts and in medium overall yield (Table 1, entry 1). Acetonitrile as the reaction media did not substantially change the product **5** and **6** ratio

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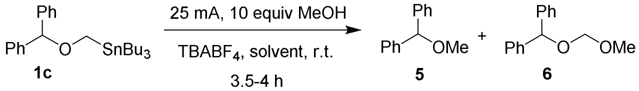
nor the yield (Table 1, entry 2). Considerable improvement of carbenium ion reaction product **5** formation was achieved in dichloromethane as reaction solvent (Table 1, entry 3). Notably, almost complete selectivity for the desired product **5** formation was observed performing the reaction in HFIP (Table 1, entry 4).[18,19]

Table 1. Electrochemical activation of substrate **1c** in the presence of MeOH

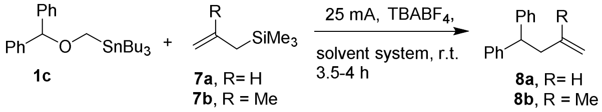


Entry	Solvent	ratio **5 : 6**	yield of **5**&**6**, %[a]
1	MeOH	1 : 1.1	50
2	MeCN	1.3 : 1	50
3	CH_2Cl_2	7.5 : 1	85
4	HFIP	>99 : 1	73

[a] Total ^{1}H-NMR yield of products **5** and **6** using 1,4-bis-trichloromethylbenzene as the internal standard

Next the electrochemical activation of the substrate **1c** was performed in the presence of allylsilanes **7a,b**[20] which would lead to a useful C-C bond formation (Table 2).[21] Using HFIP as the solvent and proton donor, the reaction of stannylmethylether **1c** with allylsilane **7a** provided the desired product **8a**, albeit in a low yield due to the formation of several side products (Table 2, entry 1). Dichloromethane as the solvent with HFIP as an additive proved to be a more suitable reaction medium for an electrochemically induced reaction of stannylmethylether **1c** with allylsilanes **7a,b** to give the expected carbenium ion allylation products **8a,b** in good yields (Table 2, entries 2,3).

Table 2. Electrochemical activation of substrate **1c** in the presence of allylsilanes

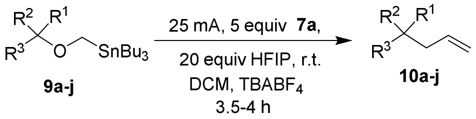


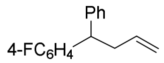
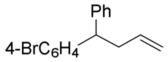
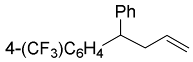
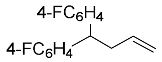
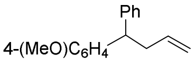
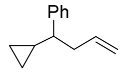
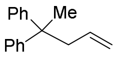
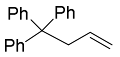
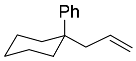
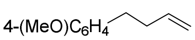
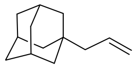
Entry	**7**, Solvent system	**8**, yield%
1	**7a**, HFIP	**8a**, 40 (NMR) [a]
2	**7a**, CH_2Cl_2, 20 equiv HFIP	**8a**, 87 (isolated)
3	**7b**, CH_2Cl_2, 20 equiv HFIP	**8b,** 64 (isolated)

[a] ^{1}H-NMR yield using 1,4-bis-trichloromethylbenzene as the internal standard

Substrate scope for allylation of the carbenium ions was investigated using optimal reaction conditions for the electrochemical activation of stannylmethyl ether (Table 3).

Table 3. Substrate scope for the reaction with allylsilane under electrochemical activation conditions



Entry	Product	**10**, yield %
1		**10a**, 74
2		**10b**, 79
3		**10c**, 76
4		**10d**, 81
5		**10e**, 72
6		**10f**, 91
7		**10g**, 26 [a]
8		**10h**, 42 [b]
9		**10i**, 75
10		**10j**, 14
11		**10k**, 0

[a] 1,1-Diphenylethylene (20%) was isolated as a side product
[b] ^{1}H-NMR yield using 1,4-bis-trichloromethylbenzene as the internal standard; obtained as an inseparable mixture with triphenylmethane.

Diphenylmethyl carbenium ion reaction products **10a–e** were obtained from substrates **9a–e** in good yields bearing both electron withdrawing and electron donating substituents in phenyl rings (Table 3, entries 1–5). The phenylcyclopropylmethyl carbenium ion generated from the substrate **9f** was also efficiently allylated to give product **10f** (Table 3, entry 6). Tertiary carbenium ions generated from ethers **9g,h** provided the allylation products **10g,h** in low yield

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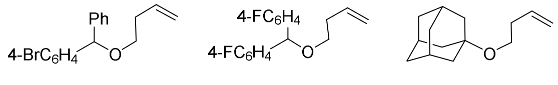
(Table 3, entries 7,8). However, the less stable phenylcyclohexyl cation generated from substrate **9i** gave the allylated product **10i** in good yield (Table 3, entry 9). Benzylic ether **9j** gave product **10j** in poor yield while no expected product **10k** was obtained from adamantyl ether **9k** (Table 3, entries 10, 11). Poor performance of these substrates can be attributed to a slow fragmentation of the oxonium ion **2** to carbenium ion **3** due to the decreased stability of the latter. Oxonium ion allylation by-products **11**–**13** were isolated in the case of substrates **9b,d,k** providing less stable carbenium ions. Notably, in the case of adamantyl ether **9k**, homoallylether **13** formed as the major product.



11, 6% **12**, 6% **13**, 44%

Figure 2. Isolated oxonium ion allylation products

Hydrogen bonding properties of HFIP[22,23] can potentially promote the ionization of ethers **7** and **9** to give carbenium ions without electrochemical activation. Therefore, several control reactions were performed in the absence of electric current (Table 4). Indeed, product **8a** and **10a,f,h** formation was observed, however, the reaction was very slow and lower yielding. These results indicate that electrochemical activation of the substrates is crucial for efficient carbenium ion generation.

Table 4. Product **8** and **10** formation without electrochemical activation of the substrate

Entry	time	product, NMR yield %
1	18 h	**8a**, 25
2	18 h	**10a**, 5
3	18 h	**10f**, 60
3	3 days	**10h**, 33

[a] ^{1}H-NMR yield using 1,4-bis-trichloromethylbenzene as the internal standard

Conclusions

In summary, we have demonstrated that carbenium ions can be formed in the presence of nucleophiles by fragmentation of electrochemically generated oxonium ions. To achieve an acceptable oxidation potential of the substrate, the tributylstannylmethyl group was found as an efficient electroauxiliary for the oxonium ion formation. The application of this concept was demonstrated for allylation of carbenium ions electrochemically generated from a range of stannylmethyl ethers in the presence of allylsilanes. Additional investigations are in progress to expand the scope of this reaction with other nucleophiles compatible with the oxidation potential needed for substrate activation.

Conflicts of interest

There are no conflicts to declare.

Acknowledgements

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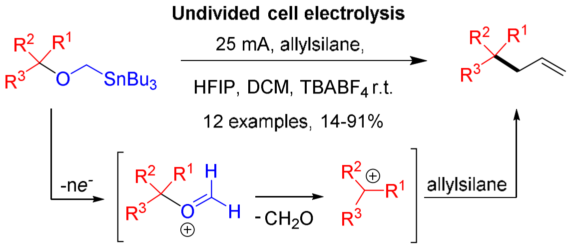

Fragmentation of electrochemically generated oxonium ions can be exploited to form carbenium ions at low oxidation potential in the presence of a nucleophile such as allylsilane