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Thermal and Catalytic Transylidations between Halonium Ylides and Synthesis and Reaction of Stable Aliphatic Chloronium Ylides

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Iodonium ylides serve as excellent progenitors for generation of singlet carbenes[1] because of the hyper-leaving group ability of aryl-λ^3-iodanyl groups.[2] Under thermal, catalytic, or photochemical conditions, they transfer the alkylidene groups to a wide range of heteroatom nucleophiles involving nitrogen heterocycles, phosphines, arsines, sulfides, sulfoxides, and selenides, providing a useful preparative method for pyridinium, phosphonium, and sulfonium ylides, etc.[3] In spite of the surging interest and activity in ylide chemistry, the transylidation between halonium ylides, in which carbenes generated from halonium ylides are captured by alkyl and aryl halides, remains unknown except for an intramolecular transylidation of iodonium ylides.[4] Intermediate formation of labile alkyliodonium ylides via ylide transfer of aryliodonium ylides has been proposed but with no evidence.[5,6]

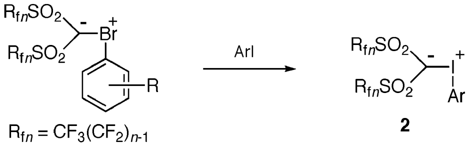
We report herein, for the first time, unambiguous experimental evidence for the intermolecular transylidation between halonium ylides under thermal and catalytic conditions, which makes it possible to synthesize a hitherto unknown kind of aliphatic chloronium ylides **3** as well as a variety of bromonium and iodonium ylides **1** and **2**. Very interestingly, compared to the bromonium and iodonium ylides **1a** and **2a**, the chloronium ylide **3a** serves as a much better progenitor for generation of carbenes (or carbenoids) and efficiently undergoes cyclopropanation of olefins such as cyclooctadiene under uncatalyzed thermal conditions.

Heating a 0.1 M solution of bromonium ylide **1b**,[7] prepared from *p*-trifluoromethylphenyl(difluoro)-λ^3-bromane by the ligand exchange with bis(trifluoromethylsulfonyl)methane, in iodobenzene at 160 °C for 1 h resulted in the smooth intermolecular transylidation yielding the iodonium ylide **2a** (Ar = Ph, $R_{fn} = CF_3$) in 87% yield after purification by silica gel column chromatography (Scheme 1 and Table 1, entry 5). Even at 130 °C, the ylide transfer to the iodide takes place, but the rate considerably slows down. In a marked contrast, use of the iodonium ylide **2g** with the p-CF_3 group instead of the bromonium ylide **1b** did not show any evidence for carbene transfer to iodobenzene under the conditions, and the ylide **2g** was recovered quantitatively. This is the first firmly established example indicating that the intermolecular transylidation between halonium ylides takes place.

Iodonium ylides **2b**−**g** with electron-donating (MeO, Me) and -withdrawing substituents (CF_3, F, Cl, Br) were prepared in good to high yields. Highly nucleophilic *p*-methoxyiodobenzene undergoes more efficiently the carbene capture at a lower temperature (140 °C) compared to our standard conditions (Table 1, entries 6 and 7).

In the bromonium to iodonium ylide exchange, rhodium(II) acetate was found to be the catalyst of choice for carbenoid capture by iodobenzenes: thus, addition of a catalytic amount (5 mol %) of $Rh_2(OAc)_4$ dramatically decreased the reaction temperature, and high yields of iodonium ylides **2** were obtained at 40 °C for 5 h (Table 1, entries 17−20). Traditional copper catalysts $Cu(acac)_2$ and CuI required longer reaction times, except for CuCN.

Scheme 1



$R_{fn} = CF_3(CF_2)_{n-1}$

2

1a: $n = 1$, R = H; **1b**: $n = 1$, R = p-CF_3;
1c: $n = 4$, R = p-CF_3

Table 1. Transylidation of Bromonium **1** to Iodonium Ylides **2**[a]

entry	1	ArI	additive[c]	temp (°C)	time (h)	2	yield[b] (%)
1	**1a**	PhI		160	1	**2a**	32(36)[d]
2	**1b**	PhI		130	1	**2a**	(56)[d]
3	**1b**	PhI		140	1	**2a**	(76)[d]
4	**1b**	PhI		150	1	**2a**	(76)
5	**1b**	PhI		160	1	**2a**	87(89)
6	**1b**	p-$MeOC_6H_4I$		160	1	**2b**	46
7	**1b**	p-$MeOC_6H_4I$		140	1	**2b**	70
8	**1b**	p-MeC_6H_4I		160	1	**2c**	89
9	**1b**	p-FC_6H_4I		160	1	**2d**	79
10	**1b**	p-ClC_6H_4I		160	1	**2e**	78
11	**1b**	p-BrC_6H_4I		160	1	**2f**	65
12	**1b**	p-$CF_3C_6H_4I$		160	1	**2g**	89
13	**1c**	PhI		160	1	**2h**	71
14	**1b**	PhI	CuI	40	5	**2a**	(10)[d]
15	**1b**	PhI	$Cu(acac)_2$	40	5	**2a**	(63)[d]
16	**1b**	PhI	CuCN	40	5	**2a**	(93)[d]
17	**1b**	PhI	$Rh_2(OAc)_2$	40	5	**2a**	94(100)
18	**1b**	p-MeC_6H_4I	$Rh_2(OAc)_2$	40	5	**2c**	100
19	**1b**	p-FC_6H_4I	$Rh_2(OAc)_2$	40	5	**2d**	99
20	**1b**	p-$CF_3C_6H_4I$	$Rh_2(OAc)_2$	40	5	**2g**	96

[a] Conditions: ylide **1** (0.1 M), Ar. [b] Isolated yields. Numbers in parentheses are ^1H NMR yields. [c] Metal catalyst (5 mol %). [d] Recovered ylides **1**: 8, 34, 3, 89, 18, and 3% for entries 1−3 and 14−16.

The relative rates of this thermal transylidation for a series of substituted iodobenzenes with *p*-Me, *p*-Cl, and p-CF_3 groups were measured at 140 °C for 3 h by competitive reactions, in which a mixture of each 40-fold excess of two competing substrates was used (Scheme S1). A control experiment showed that, in the competitive ylide transfer of the bromonium ylide **1b** to PhI and p-$CF_3C_6H_4I$, ratios of the products **2a** and **2g** were nearly constant for the samples taken at intervals through several half-lives (Figure S1). Furthermore, transylidations between the iodonium ylides **2a** and **2c** (or **2g**) were found to be negligibly small under the conditions (Schemes S2 and S3). Electron-releasing *p*-Me group increases the relative rate k_{rel} of the carbene transfer: 1.33 (p-MeC_6H_4I); 1.0 (PhI); 0.82 (p-ClC_6H_4I); 0.52 (p-$CF_3C_6H_4I$). Hammett plot showed a good correlation of the relative rate factors with σ_p constants and gave the reaction constant $\rho = -0.54$ ($r = 0.99$). A larger negative ρ value of -0.91 ($r = 1.0$) was evaluated in the Rh(II)-catalyzed carbenoid transfer reaction at 40 °C for 1 h (Figure S2).[8] The fact that the rate of uncatalyzed decomposition of the ylide **1b** is independent of the concentrations of iodide (PhI)

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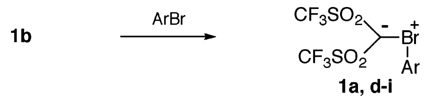
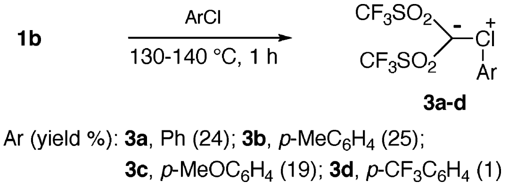
Table 2. Transylidation between Bromonium Ylides **1**[a]



entry	ArBr	temp (°C)	time (h)	**1**	yield[b] (%)
1	PhBr	130	4	**1a**	48(48)[e]
2[c,d]	PhBr	40	5	**1a**	6(7)[e]
3	*p*-MeOC_6H_4Br	150	1	**1d**	55(64)[e]
4	*o*-MeOC_6H_4Br	150	1	**1e**	47(58)[e]
5	*p*-MeC_6H_4Br	150	1	**1f**	60(66)
6[c]	*p*-MeC_6H_4Br	150	1	**1f**	(0)
7	3,5-$Me_2C_6H_3$Br	130	5	**1g**	44(51)[e]
8	*p*-FC_6H_4Br	130	1	**1h**	(2)
9[c]	*p*-FC_6H_4Br	130	2	**1h**	65(72)[e]
10[c]	*p*-ClC_6H_4Br	130	1	**1i**	44(43)[e]

[a] Conditions: ylide **1b** (0.1 M), air. [b] Isolated yields. Numbers in parentheses are ^1H NMR yields. [c] Under Ar. [d] $Rh_2(OAc)_2$ (5 mol %). [e] Recovered ylide **1b**: 7, 53, 5, 15, 3, 19, and 42% for entries 1−4, 7, 9, and 10.

Scheme 2

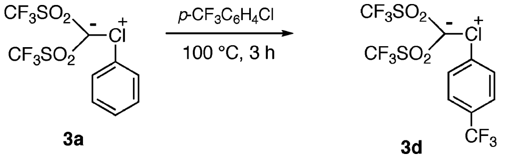


is not compatible with a carbenoid mechanism, which involves a rate-limiting nucleophilic attack of iodobenzene on the ylidic carbon atom of **1b** (Figure S3). A small negative ρ value for the uncatalyzed thermal transylidations of bromonium **1b** to iodonium ylides **2** would probably suggest generation of a reactive carbene :$C(SO_2CF_3)_2$, being electrophilic in nature, as well as an early transition state for carbene transfer.

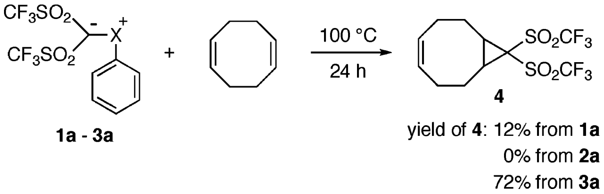
Intermolecular transylidation between bromonium ylides **1** takes place smoothly under thermal conditions; thus, heating a solution of the ylide **1b** in bromobenzene at 130 °C for 4 h in the air afforded the bromonium ylide **1a** in 48% yield, whereas Rh(II)-catalyzed conditions gave poor results (Table 2, entries 1 and 2). A variety of substituted bromonium ylides **1d**−**i** were prepared in 44−65% yields. It is noted that the transylidation to electron-rich *p*-MeC_6H_4Br occurs readily in the air but not under Ar, while interestingly, the reverse was found for that to electron-deficient *p*-FC_6H_4Br (compare entries 5, 6, 8, and 9).

In 1954, a transient formation of a highly labile chloronium ylide was suggested in the thermal decomposition of ethyl diazoacetate in benzal chloride.[9] Stable aromatic chloronium ylides, in which the ylide carbanions were stabilized through aromatization in heterocyclic rings, have been prepared by the thermolysis of diazodicyanoimidazole in chlorobenzene;[6a] however, no stable and well-established aliphatic chloronium ylides are known. We are very pleased to find that chlorobenzenes also serve as acceptor molecules in these alkylidene transfer reactions of the bromonium ylide **1b**, yielding aliphatic chloronium ylides **3** (Scheme 2); thus, under thermal conditions, chlorobenzene gave the chloronium ylide **3a** in 24% yield after purification by silica gel preparative TLC. Chloronium ylides **3b** and **3c** with electron-donating groups (*p*-Me and *p*-MeO) on the aromatic ring were also prepared in 19−25% yields, but the attempted alkylidene transfer to chlorobenzene with an electron-withdrawing *p*-CF_3 group, yielding the ylide **3d**, was found to be fruitless. Use of the more reactive chloronium ylide **3a** in the transylidation reaction instead of the bromonium ylide **1b**, however, increased the yield of the chloronium ylide **3d** to 15% (Scheme 3).

Scheme 3



Scheme 4



Cyclopropanation of olefins with iodonium ylides usually requires use of a transition metal catalyst such as Rh(II) or Cu to generate reactive metallocarbene intermediates.[3a,10] In fact, the attempted reaction of cyclooctadiene with iodonium ylide **2a** recovered it unchanged under uncatalyzed thermal conditions (100 °C, 24 h, Scheme 4). Use of the bromonium ylide **1a** afforded the cyclopropane **4** but in a low yield (12%), whereas the thermal reaction of the chloronium ylide **3a** with cyclooctadiene took place smoothly, probably via generation of reactive carbene, and produced **4** in 72% yield. A greater leaving group ability of the λ^3-chloranyl and λ^3-bromanyl groups compared to that of the λ^3-iodanyl group seems to be responsible for the observed differences in reactivity between these halonium ylides.[11]

In conclusion, thermal and metal-catalyzed transylidation of halonium ylides provides us a tool for the synthesis of a variety of halonium ylides, including the aliphatic chloronium ylide, which serves as a nice progenitor for generation of carbenes (or carbenoids).

Supporting Information Available: Experimental details, Schemes S1−S3, and Figures S1−S3. This material is available free of charge via the Internet at http://pubs.acs.org.

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