Unexpected Chemoselective Debromination and Reduction of 1,1-Dibromo-1-alkenes Mediated by Samarium Metal in Methanol

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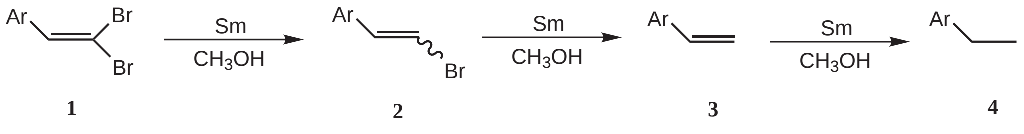
Abstract: An unexpected samarium metal mediated chemoselective debromination and reduction of 1,1-dibromo-1-alkenes in methanol has been developed, which generates vinyl monobromides, alkenes, and alkanes respectively with appropriate molar ratio of samarium to 1,1-dibromo-1-alkene.

Key words: samarium metal, 1,1-dibromo-1-alkenes, debromination, reduction, methanol

Since its introduction by Kagan and his co-workers, samarium(II) iodide (SmI_2) has been extensively investigated as a powerful one-electron transfer reducing agent in synthetic organic chemistry and many examples have been reported of its use in the reduction of various functional groups.[1] Though SmI_2 is a useful reagent, some problems are encountered when it is used as a reductant. For example, it is expensive, it needs delicate treatment and careful storage because it is very sensitive to air oxidation. On the other hand, metallic samarium is stable in air and has stronger reducing power ($Sm^{3+}/Sm = -2.41$ V) than that of SmI_2 ($Sm^{3+}/Sm^{2+} = -1.55$ V) and it has been noted recently that cheaper and more convenient metallic samarium can be used directly as a reductant instead of SmI_2 in organic synthesis.[2] Because the samarium atoms on the accessible solid surface are not sufficiently reactive,[3] a lot of activating agents have been used to activate metallic samarium to mediate the reactions.[4] Recently, Yanada reported that a reductive dehalogenation of aliphatic *vic*-dihalides with samarium metal is accelerated in a methanolic medium.[5] However, to the best of our knowledge, there has been no report in which Sm/CH_3OH system is used for reductive debromination and reduction of 1,1-dibromo-1-alkenes.

1,1-Dibromo-1-alkenes, easily prepared from a simple reaction of an aldehyde with carbon tetrabromide and triphenylphosphine,[6] are important starting materials in organic synthesis. There are a few reports on the Pd-catalyzed cross coupling reaction of 1,1-dibromo-1-alkenes with boronic acids,[7] organostannanes,[8] alkynes and vinylalanes,[9] and organozinc and Grignard reagents.[10] On the other hand, Pd-catalyzed hydrogenolysis of 1,1-dibromo-1-alkenes with tributyltin hydride,[11] reductive reaction with hydride anion,[12] reductive debromination with indium metal to vinyl monobromides,[13] and reductive debromination followed rearrangement to alkynes with SmI_2 in C_6H_6–HMPA[14] have been also explored. Here, we wish to report an unexpected chemoselective debromination and debromination followed reduction of 1,1-dibromo-1-alkenes promoted by samarium metal in methanol, which yields vinyl monobromides, alkenes, and alkanes respectively with appropriate molar ratio of samarium to 1,1-dibromo-1-alkenes (Scheme 1).

Initial experiments on the reaction of 1,1-dibromo-1-alkenes with samarium metal in methanol revealed the effect of reaction temperature on reductive debromination and reduction of vinyl dibromides. The results indicated that when the reaction is carried out at room temperature, reductive debromination needs longer reaction time to complete and reduction step (**3** → **4**) is difficult, even in the presence of excess samarium metal and for longer reaction time. Meanwhile, a high temperature leads to the poor chemoselectivity for the reduction. The optimized reaction temperature falls in the range of 45–60 °C. It is surprising to find that the amount of samarium metal added to the reaction plays a very important role in the chemoselectivity of the reduction. The experimental results are listed in Table 1. 4-(2,2-Dibromovinyl)chlo-



Scheme 1

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robenzene was chosen as the model compound for this survey. In our investigation, samarium metal was added to the methanolic solution of 4-(2,2-dibromovinyl)chlorobenzene in equal molar quantities, as a result of reductive debromination product **2** isolated in moderate yield, along with unreacted starting material. When the amount of samarium metal was increased to 1.5 mole times of 1,1-dibromo-1-alkene, **2** was formed in excellent yield and *E*-isomer was in the majority. Continuing our study to increase samarium metal amount to 2 mole times of 1,1-dibromo-1-alkene, a mixture of **2** and **3**, a secondary reductive debromination product, was generated. This result is different from the reaction of vinyl dibromides with samarium diiodide, organolithium or organozincates.[15] While 3 mole times of Sm was added, **3**, an alkene, was given in excellent yield. When amount of samarium was increased up to 4 mole times, it was found that reductive debromination followed reduction product **4** was produced,[16] along with **3**. In the presence of excess amount of samarium metal (≥5.5 times) and at higher reaction temperature, **4** was obtained quantitatively.

A series of 1,1-dibromo-1-alkenes were successfully reduced to the desired products with metallic samarium in methanol without any activator. The results are summarized in Table 2. As seen in Table 2, 1,1-dibromo-1-alkenes can be easily reduced to the corresponding vinyl monobromides, alkenes or alkanes respectively by metallic samarium with appropriate molar ratio of samarium to 1,1-dibromo-1-alkenes in methanol with excellent yields. Substituent effect was also investigated in series of 2-aryl-1,1-dibromo-1-alkenes. The results indicated that the reaction is relatively insensitive to the electronic characteristics of a substituent group and its location on the aromatic rings. However, 2-alkyl-1,1-dibromo-1-alkenes failed to react with samarium metal under reaction conditions. Halogen other than bromine was also examined. 1,1-Dichloro-1-alkenes are far less reactive, probably due to the stronger carbon-chlorine bond. Further study on the reduction of other unsaturated or sensitive functional groups under the reaction conditions is going and will be reported in due course.

During our investigation, we found that a dark blue solution was formed when the reaction was conducted in the presence of metallic samarium and methanol. It is reasonable that the reaction may be carried out mainly with Sm(II) species generated from the mixture of samarium and methanol. The possible mechanism for the reaction is proposed in Scheme 2. It may involve the single-electron-transfer (SET) process. An intermediate free radical (**I**) may be formed by a SET under the reaction conditions. This intermediate (**I**) subsequently reacts with Sm(II) to form an anion (**II**) and then (**II**) is protonated to yield vinyl monobromide **2**. Repeating the processes, **3** is formed in the same manner. In the presence of excess samarium and methanol, **3** is reduced to alkane **4**. The more detail study about the reaction mechanism is in progress in our laboratory.

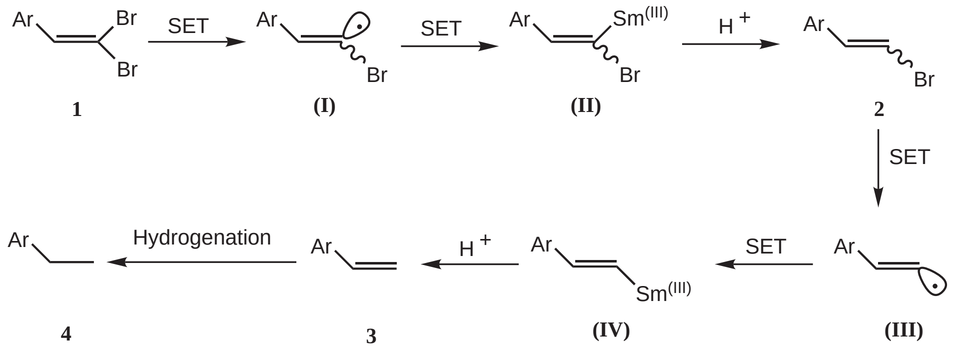
The general procedure is as follows: A mixture of 1,1-dibromo-1-alkenes (0.50 mmol) and samarium metal powder (the amount of samarium metal added is dependent on the desired product) in methanol (5 mL) was stirred vigorously at certain temperature for a certain period of time under nitrogen atmosphere. The color of the solution turned to dark blue after the initiating the reaction with hydrogen evolution. After the reaction (about 6 h, reaction progress monitored by TLC), hydrochloric acid (0.5 mol/L, 2 mL) was added to quench the reaction and the mixture was extracted with ether (10 mL × 2). After the organic layer was dried with anhydrous sodium sulfate, the solvents were evaporated under reduced pressure. The product was purified by flash chromatography to yield the desired products.

In conclusion, we have demonstrated that Sm/CH_3OH can be used for the chemoselective debromination and reduc-

Table 1 Reaction Conditions of 4-(2,2-Dibromovinyl)chlorobenzene with Samarium Metal in Methanol[a]

Entry	Molar ratio of Sm:**1**	Temp. (°C)	Yield (%)[b]			
			2 (*Z*/*E*)[c]	**3**	**4**	**1**
1	1:1	45	64 (29/71)	–	–	33
2	1.5:1	45	96 (31/69)	–	–	–
3	2:1	45	64 (30/70)	(35)	–	–
4	3:1	45	–	(98)	–	–
5	4:1	45	–	(65)	(35)	–
6	5.5:1	45	–	(32)	(68)	–
7	5.5:1	60	–	–	(100)	–
8	7:1	60	–	–	(100)	–

[a] Reaction scale: 4-(2,2-dibromovinyl)chlorobenzene (0.50 mmol), methanol (5 mL), and reaction time 6 h.
[b] Isolated yields and GC yields in parentheses.
[c] *Z/E* ratio was determined by GC and NMR.



Scheme 2

tion of 1,1-dibromo-1-alkenes. Vinyl monobromides, alkenes, or alkanes can be obtained respectively from the reaction of 1,1-dibromo-1-alkenes and samarium metal with appropriate molar ratio of samarium to 1,1-dibromo-1-alkene in methanol. The notable advantages of this method are mild reaction conditions, novel excellent chemoselectivity and quantitative yields. It may be a new way for the application of Sm/CH_3OH in reduction of the unsaturated functional groups in organic synthesis.

Table 2 Reductive Debromination and Reduction of 1,1-Dibromo-1-alkenes with Samarium Metal in Methanol[a]

Entry	Dibromides	Reaction Conditions	Yield (%)[b]		
			2 (*Z*/*E*)[c]	**3**	**4**
1	$C_6H_5C=CBr_2$	Sm (1.5 equiv), CH_3OH (5 mL), 45 °C, 6 h	97 (33/67)	–	–
2	$C_6H_5C=CBr_2$	Sm (3.0 equiv), CH_3OH (5 mL), 45 °C, 6 h	–	(98)	–
3	$C_6H_5C=CBr_2$	Sm (5.5 equiv), CH_3OH (5 mL), 60 °C, 6 h	–	–	(100)
4	*p*-$ClC_6H_4C=CBr_2$	Sm (1.5 equiv), CH_3OH (5 mL), 45 °C, 6 h	96 (31/69)	–	–
5	*p*-$ClC_6H_4C=CBr_2$	Sm (3.0 equiv), CH_3OH (5 mL), 45 °C, 6 h	–	94 (97)	–
6	*p*-$ClC_6H_4C=CBr_2$	Sm (5.5 equiv), CH_3OH (5 mL), 60 °C, 6 h	–	–	(100)
7	*p*-$CH_3C_6H_4C=CBr_2$	Sm (1.5 equiv), CH_3OH (5 mL), 45 °C, 6 h	95 (40/60)	–	–
8	*p*-$CH_3C_6H_4C=CBr_2$	Sm (3.0 equiv), CH_3OH (5 mL), 45 °C, 6 h	–	(98)	–
9	*p*-$CH_3C_6H_4C=CBr_2$	Sm (5.5 equiv), CH_3OH (5 mL), 60 °C, 6 h	–	–	(100)
10	*m*-$ClC_6H_4C=CBr_2$	Sm (1.5 equiv), CH_3OH (5 mL), 45 °C, 6 h	98 (30/70)	–	–
11	*m*-$ClC_6H_4C=CBr_2$	Sm (3.0 equiv), CH_3OH (5 mL), 45 °C, 6 h	–	(99)	–
12	*m*-$ClC_6H_4C=CBr_2$	Sm (5.5 equiv), CH_3OH (5 mL), 60 °C, 6 h	–	–	(100)
13	*o*-$FC_6H_4C=CBr_2$	Sm (1.5 equiv), CH_3OH (5 mL), 45 °C, 6 h	95 (22/78)	–	–
14	*o*-$FC_6H_4C=CBr_2$	Sm (3.0 equiv), CH_3OH (5 mL), 45 °C, 6 h	–	(97)	–
15	*o*-$FC_6H_4C=CBr_2$	Sm (5.5 equiv), CH_3OH (5 mL), 60 °C, 6 h	–	–	(100)
16	α-$C_{10}H_7C=CBr_2$	Sm (1.5 equiv), CH_3OH (5 mL), 45 °C, 6 h	97 (25/75)	–	–
17	α-$C_{10}H_7C=CBr_2$	Sm (3.0 equiv), CH_3OH (5 mL), 45 °C, 6 h	–	97	–
18	α-$C_{10}H_7C=CBr_2$	Sm (5.5 equiv), CH_3OH (5 mL), 60 °C, 6 h	–	–	98

[a] Reaction scale: 1,1-dibromo-1-alkene (0.50 mmol).

[b] Isolated yields and GC yields in parentheses.

[c] *Z/E* ratio was determined by GC and NMR.

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