The Hydrodebromination of 1,1-Dibromoalkenes via Visible Light Catalysis

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The Hydrodebromination of 1,1-Dibromoalkenes via Visible Light Catalysis

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ABSTRACT

Vinyl bromides are versatile synthetic intermediates and widely applied in organic synthesis and pharmaceuticals. Herein, a hydrodebromination reaction of 1,1-dibromoalkenes was established via visible light catalysis. A variety of structurally different vinyl bromides were obtained in moderate to excellent yields.

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Introduction

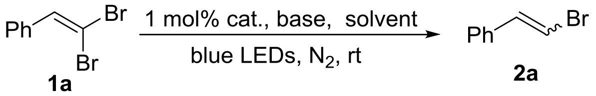
Vinyl bromides are important organic synthesis intermediates for synthesizing alkynes, heterocycles and other chemicals by transition metal-mediated cross-coupling reactions.[1] The hydrodebromination of 1,1-dibromoalkenes which can be conveniently prepared from aldehydes and carbon tetrabromide is a classical method for the synthesis of vinyl bromides.[2] Normally, metal-halogen exchange of organic metal reagents,[3] organic phosphorus reduction,[4] and transition metal reductive catalysis[5] were available strategies for the C-Br bond cleavage of 1,1-dibromoalkenes. These methods were efficient for preparing vinyl bromides, however, some had the drawbacks such as poor applicability of substrates and use of toxic, air sensitive reagents. From these points of view, it is necessary to develop new simple and mild methods for the preparation of vinyl bromides.

Recently, visible light photocatalysis has aroused more and more interest due to its advantages of good substrate compatibility, unique reaction properties, and mild reaction conditions.[6] Different from the traditional chemical pathway, visible light photocatalysis has exhibited special chemical reaction characteristics via single electron transfer.[7] Since MacMillan firstly reported the direct asymmetric alkylation of aldehydes by merging photoredox catalysis with organocatalysis in 2008,[7a] reports about visible light photocatalysis have shown a rapid increase. Various efficient chemical reactions via visible light photoredox catalysis have been developed. Among these, the reductive dehalogenation has become an important research topic.[8] Visible light-mediated photoredox catalysis combining with different hydrogen donor has been applied to the reduction cleavage of C(*sp*^{3})-X and C(*sp*^{2})-X bonds.[9] For example, Stephenson reported a mild hydrodebromination of C(*sp*^{3})-Br bonds and C(*sp*^{2})-Br bonds, which combined visible light-mediated photoredox catalysis with silane-mediated atom transfer.[10] Duan achieved the reduction of aromatic halides by combining photoactive PDI with metal-organic polymer.[11] Herein, we[12] wish to report a hydrodebromination of 1,1-dibromoalkenes through visible light photocatalysis.

Result and discussion

Initially, 2,2-dibromostyrene **1a** was chosen as a model substrate. Under the irradiation of blue LEDs, the reaction was performed in DCE with 1% Ir(ppy)$_2$(dtbbpy)PF$_6$ as a photocatalyst and Et$_3$N as a base and reductant. Excitingly, 2-bromostyrene **2a** was obtained in 90% GC yield. The over reduction product styrene was not detected in the reaction. Then different bases such as ^{i}Pr$_2$NEt and DABCO were surveyed, which showed that ^{i}Pr$_2$NEt was more positive (entries 1-3). Screening of several solvents, including DMF, DMSO, and NMP, showed disappointing result (entries 4-8). The expected reaction did not occur in toluene maybe due to the poor solubility of photocatalyst (entry 9). Based on these, photocatalysts Ru(bpy)$_3$Cl$_2$•6H$_2$O, Ru(bpy)$_3$(BF$_4$)$_2$, Ir(ppy)$_3$, and Ir(ppy)$_2$(bpy)BF$_4$ were tried (entries 10-13). The GC yield could be up to 93% when Ir(ppy)$_2$(bpy)BF$_4$ was used as the catalyst. Lastly, control experiments indicated that irradiation and photocatalysts were essential for the reaction (entries 14-15).

Table 1: Optimization of the reaction conditions[a]



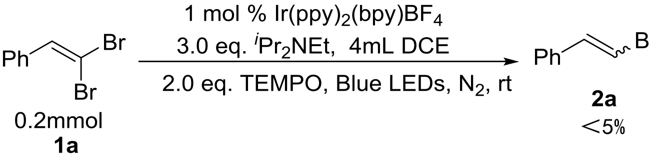
1a **2a**

Entry	Base	Solvent	Photocatalyst	Yield (%)[b]
1	Et$_3$N	DCE	Ir(ppy)$_2$(dtbbpy)PF$_6$	90
2	^{i}Pr$_2$NEt	DCE	Ir(ppy)$_2$(dtbbpy)PF$_6$	93
3	DABCO	DCE	Ir(ppy)$_2$(dtbbpy)PF$_6$	71
4	^{i}Pr$_2$NEt	DMSO	Ir(ppy)$_2$(dtbbpy)PF$_6$	80
5	^{i}Pr$_2$NEt	DMF	Ir(ppy)$_2$(dtbbpy)PF$_6$	84
6	^{i}Pr$_2$NEt	NMP	Ir(ppy)$_2$(dtbbpy)PF$_6$	44
7	^{i}Pr$_2$NEt	DCM	Ir(ppy)$_2$(dtbbpy)PF$_6$	91
8	^{i}Pr$_2$NEt	MeCN	Ir(ppy)$_2$(dtbbpy)PF$_6$	88
9	^{i}Pr$_2$NEt	toluene	Ir(ppy)$_2$(dtbbpy)PF$_6$	0
10	^{i}Pr$_2$NEt	DCE	Ru(bpy)$_3$Cl$_2$·6H$_2$O	62
11	^{i}Pr$_2$NEt	DCE	Ir(ppy)$_3$	39
12	^{i}Pr$_2$NEt	DCE	Ru(bpy)$_3$(BF$_4$)$_2$	65
13	^{i}Pr$_2$NEt	DCE	Ir(ppy)$_2$(bpy)BF$_4$	93
14[c]	^{i}Pr$_2$NEt	DCE	Ir(ppy)$_2$(bpy)BF$_4$	0
15	^{i}Pr$_2$NEt	DCE	-	0

[a] Standard reaction conditions: **1a** (0.4 mmol), photocatalyst (0.004 mmol, 1 mol %), base (3.0 eq.), solvent (4 mL), reaction time (36 h), blue LED irradiation under N$_2$ atmosphere at ambient temperature. [b] GC yield. [c] No light.

After the best reaction conditions were established for **1a**, the substrate scope of the reaction was investigated. The substrates containing electron-donor substituents such as methyl, methoxyl could react smoothly and the corresponding products were obtained in moderate yields (**2b-2f**). The methoxyl substituent at the ortho, meta, and para positions do not matter much and the yields were satisfactory (**2b-2f**). The yields of substrates with electron-withdrawing groups on aryl rings (**2g-2l**) are not much different from those with electron-donating groups on aryl rings (**2b-2f**). When ester or cyano groups were attached to phenyl ring, the products (**2j**, **2l**) could be obtained in 67% and 49% yields, respectively. The substituents with heterocyclic groups such as thienyl, pyridyl, pyrrolyl, and indolyl groups were suitable for the reaction (**2n-2q**). The *p*-toluenesulfonyl (Ts) group was not reduced and kept in the products (**2p-2q**). The *Z*- and *E*- isomers of **2n** and **2o** could be separated by column chromatography. To our delight, aliphatic substrates also worked well and the desired products were obtained in moderate yields (**2s-2t, 2v-2w**). The reaction activity of aliphatic substrates was comparatively lower and more difficult to be reduced, so catalyst Ir(ppy)$_2$(dtbbpy)PF$_6$ with more strong reducibility was used. Interestingly, only (*Z*)-4-bromo-2,2-dimethyl-1-phenylbut-3-en-1-one **2w** was obtained under the optimal conditions, and the ketone group did not change in the reaction. The product **2u** with high *Z/E* ratio was obtained in moderate yield. Unfortunately, the reaction was very messy when nitro group was attached to phenyl ring, probably due to the reduction of nitro group under the reaction conditions.

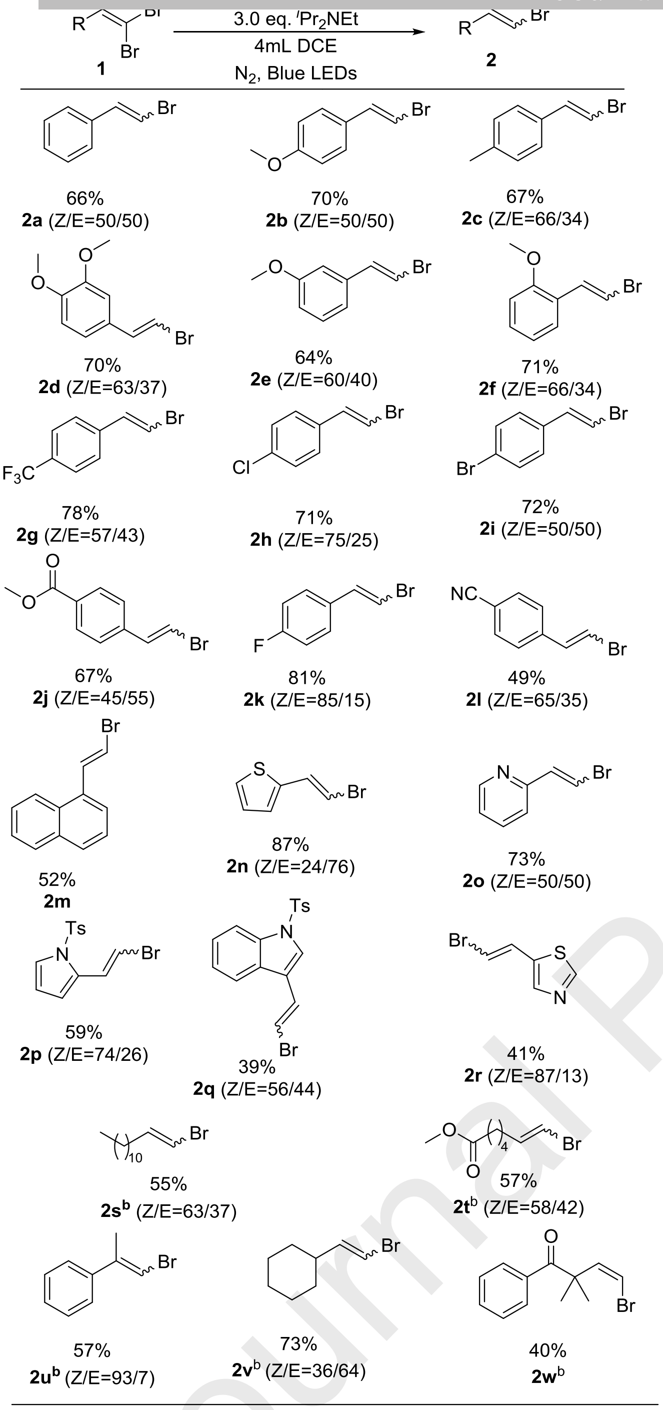
To understand the reaction mechanism, several experiments were carried out. The reaction was almost completely suppressed when 2 equivalent of TEMPO (0.4mmol) was added, which indicated that a free radical process should be involved (Scheme 1).



1a **2a**

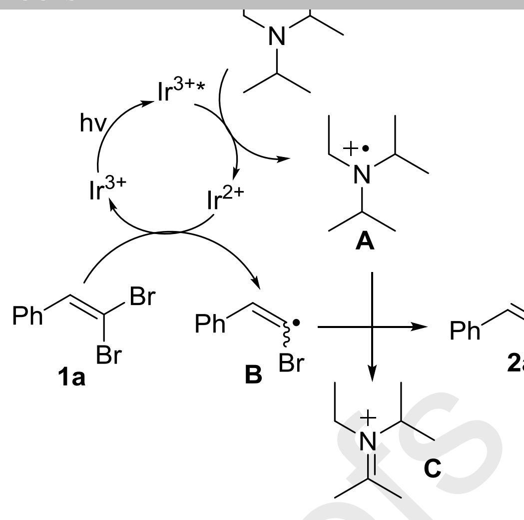
Scheme 1

Table 2: Scope of hydrodebromination reaction[a]



[a] Reaction conditions：1 (0.4 mmol), Ir(ppy)$_2$(bpy)PF$_6$ (0.004 mmol, 1 mol %), ^{i}Pr$_2$NEt (3 eq.), DCE (4 mL), reaction time (36 h), blue LED irradiation under N$_2$ atmosphere at ambient temperature. [b] Ir(ppy)$_2$(dtbbpy)PF$_6$ (0.004 mmol, 1 mol %), ^{i}Pr$_2$NEt (6 eq.).

On the basis of the literatures[9-10] and the above experimental results, a plausible reaction mechanism is proposed in Scheme 2. Initially, Ir^{3+} is excited to provide Ir^{3+*} under the irradiation of visible light. Subsequently, the excited state Ir^{3+*} is reduced to Ir^{2+} by ^{i}Pr$_2$NEt which itself is oxidized into the radical cation **A**. The carbon-bromide bond of **1a** is reductively cleavage by Ir^{2+} to generate radical **B** and bromine anion, while Ir^{2+} is oxidized to the initial Ir^{3+} to complete the catalytic cycle. Finally, radical **B** abstracts a hydrogen atom from **A** to generate the product **2a**.



Scheme 2

Conclusions

In conclusion, we have developed a new environmentally friendly strategy to synthesize a series of vinyl bromides through visible light catalytic hydrodebromination of 1,1-dibromoalkenes. It produces moderate to excellent yields of vinyl bromides under mild reaction conditions and accommodates various functional groups.

Acknowledgments

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Supplementary Material

Supplementary data (copies of ^{1}H NMR, ^{13}C NMR spectra of all products) associated with this article can be found in the online version at http://.

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Highlights

1. The hydrodebromination of 1,1-dibromoalkenes via visible light catalysis;
2. A new method for the synthesis of vinyl bromides derivatives;
3. Broad scope of the substrates, moderate to excellent yields, simple operation and mild conditions.

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