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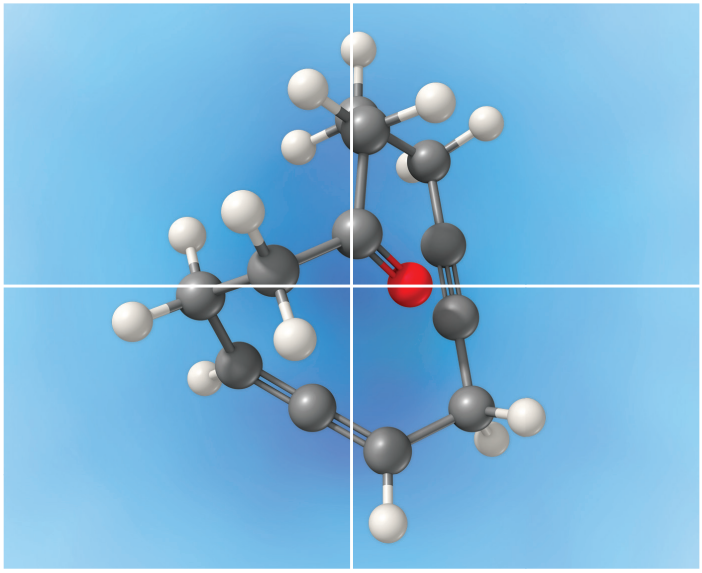

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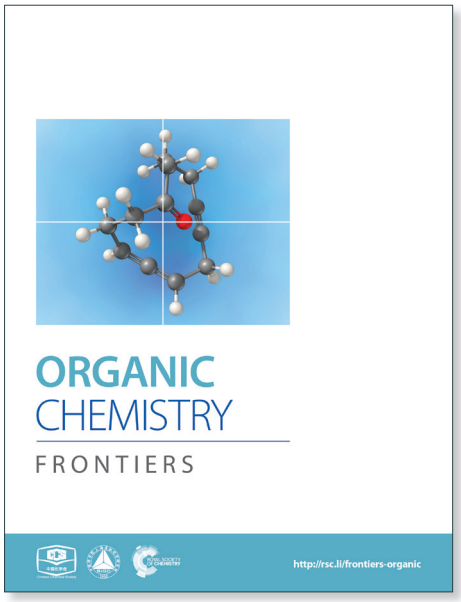

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ARTICLE TYPE

Direct Cleavage of N=N Bond of Azobenzenes by MeOTf Leading to *N*-Arylbenzimidazoles

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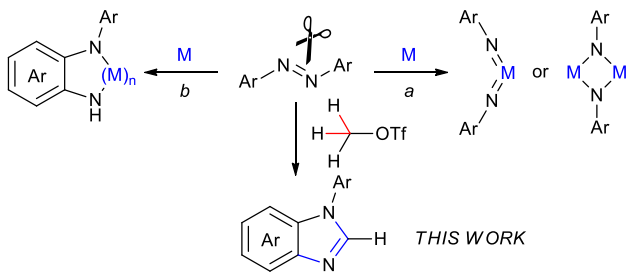
Direct cleavage of N=N bond of azo compounds by methyltriflate (MeOTf) leading to benzimidazoles has been described. In this reaction, the MeOTf serves as one carbon unit and inserts into N=N bond to form benzimidazole *via* cleavage of the N=N bond and three C-H bonds and meanwhile formation of three C-N bonds.

Introduction

The cleavage of N=N bond is of considerable importance in understanding the mechanisms of dinitrogen fixation as well as developing new transformations by using azo compounds as [RN] unit.[1] To date, most investigations on the N=N bond cleavage of the azo compounds need the assistance of transition metals. Among them, much attention has been paid on utilization of low-valent metal complexes for cleavage of the N=N bond to result in imido or μ_2/μ_3-imido metal complexes (Scheme 1, *route a*).[2] In addition, some transition-metal complexes mediated the N=N bond cleavage to result in the corresponding metal complexes with *o*-semidine (*N*-phenyl-*o*-phenylenediamine) ligand (Scheme 1, *route b*).[3] There have been also several examples of the N=N bond cleavage reactions of azobenzene with heavy main-group element Al, P, and Si compounds either in the process of *route a*[4] or *route b*[5]. Nevertheless, there is no report of direct cleavage of azo compounds by light main-group elements, to the best of our knowledge. Herein, we describe a direct cleavage of an N=N bond of azobenzenes by methyltriflate (MeOTf) leading to benzimidazole derivatives that are valuable frameworks in organic and bioorganic molecules. In this reaction, the methyl carbon atom inserts into the N=N bond to form *N*-arylbenzimidazoles *via* cleavage of the N=N bond and two sp^3 C-H bonds as well as one sp^2 C-H bond and meanwhile formation of three C-N bonds without the assistance of any metals or metalloids.

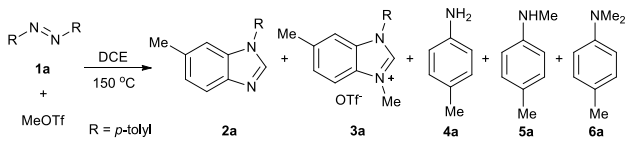


Scheme 1 N=N bond cleavage reactions of azo compounds

Result and discussion

Methyltriflate was considered as an equivalent of the methyl cation (CH_3^+) and was frequently used in the methylation reaction of heteroatom compounds.[6] During the course of our ongoing project on the construction of heterocyclic compounds,[7] we initially tried the methylation of 1,2-di-*p*-tolyldiazene **1a** by employing 1,2-dichloroethane (DCE) as solvent in a sealed tube at 150 °C. *N*-tolyl benzimidazole **2a** and benzimidazolium **3a** were detected in 38% and 8% NMR yield, respectively. Along with these, we also detected aniline **4a**, methylaniline **5a**, and dimethylaniline **6a** in 13%, 10%, and 2% NMR yield, respectively (Table 1, entry 1). Then we tried different ratio of **1a** and MeOTf, and we found the ratio of 1:1.5 to give the best yield of **2a** (entry 3). Notably, the reaction could proceed under air, and the yields were slightly decreased (entries 5-6). To confirm the structure of the product **2a**, we isolated the product **2a** and tried methylation of **2a** with MeOTf. **3a** formed quantitatively. The structure of **3a** was confirmed by single-crystal X-ray diffraction analysis and shown in Figure 1.‡

Table 1 Reaction of **1a** with MeOTf in DCE solution[a]



entry	ratio (azo : MeOTf)	NMR yield (%)				
1	1 : 1[b]	38	8	13	10	2
2	1 : 1.3[c]	47	9	17	14	3
3	1 : 1.5	51	11	16	19	3
4	1 : 2	46	16	14	20	4
5	1 : 1.5[d]	49	9	15	17	3
6	1 : 2[d]	45	16	14	19	4

[a]*Reaction condition*: 0.2 mmol **1a**, 1 mL DCE, sealed tube under N_2, 150 °C, 12 h. [b]29% **1a** remained. [c]9% **1a** remained. [d]Under air.

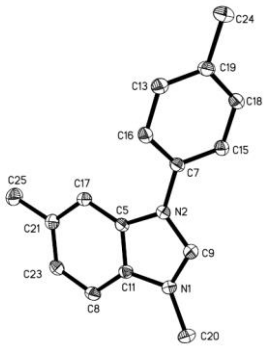
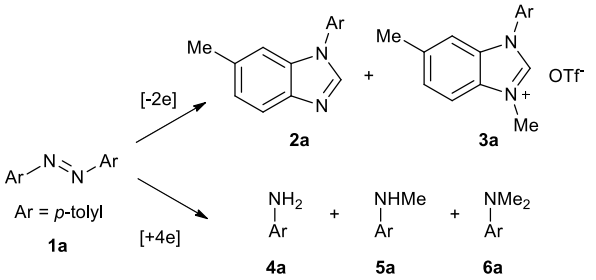


Fig.1 The X-ray crystal structure of **3a**. Thermal ellipsoids are shown at the 30% probability level; hydrogen atoms and TfO^- counterion have been omitted for clarity.

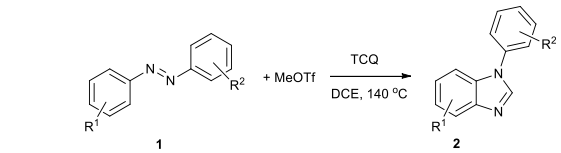
Based on the above results and redox analysis, transformation from one molecule of **1a** to **2a** and **3a** need lose two electrons, and transformation from **1a** to **4a**, **5a**, and **6a** need add four electrons. So in this reaction, about two thirds of **1a** was converted to **2a** and **3a**, and one third of **1a** was reduced to aniline derivatives **4a** and **5a**, and **6a** (Scheme 2). To prevent the formation of **4a** and **5a**, and **6a** and enhance the yield of **2a**, we tried to add oxidant in this reaction. To our delight, when 1.2 equivalent of tetrachloro-1,4-benzoquinone (TCQ) was added and the reaction mixture was heated in 140 °C for 4 h, the yield of **2a** increased to 87%.



Scheme 2 Redox analysis of the reaction

Under this condition, a study on the substrate scope was carried out, and the representative results are summarized in Table 2. Symmetrically *para*-substituted azobenzenes with methyl, methoxyl, fluoro, chloro, and bromo substituents afforded desired benzimidazoles **2a-2e** in 69% to 87% isolated yields. 4,4′-Bis(trifluoromethyl) azobenzene **1f** only afforded benzimidazole **2f** in 24% yield even increasing the temperature, prolonging the reaction time, and using two equivalents of MeOTf. 2,2′,4,4′-Tetramethyl azobenzene **1g** afforded benzimidazole **2g** in 53% yield. The lower yield may be due to the stereohindrance of the *ortho*-methyl group. 3,3′,4,4′-Tetramethyl azobenzene **1h** afforded benzimidazole **2h** in 85% yield with two isomers in 4:1 ratio. It is noteworthy that when azobenzenes without substituents in *para*-position, such as azobenzene, 2,2′-dimethyl azobenzene, and 3,3′-dimethyl azobenzene were used, complex and insoluble solids were observed without observation of benzimidazoles. Notably, when 3,3′,5,5′-tetramethyl azobenzene **1i** was used, which doesn't have *para*-substituents but stereohindrance in *para*-position, benzimidazole **2i** was formed in 12% yield. Next we tried unsymmetrically substituted azobenzenes **1j-1l**, only one product was formed. The cyclization always occurred in the electron-rich anisolyl ring, and benzimidazoles **2j-2l** were formed in 32% to 71% isolated yield. The structure of **2l** was confirmed by single-crystal X-ray diffraction analysis and shown in Figure 2.‡ When EtOTf was used instead of MeOTf, the desired 2-methylbenzimidazole **2m** was also formed in 64% yield.

Table 2 Reaction of azo compounds with alkyl triflate by using TCQ as oxidant[a]



substrate	product[b]	substrate	product[b]
1a, $R^1 = R^2$ = 4-Me	**2a**, 87%	**1j**, R^1 = 4-MeO, R^2 = 4-Me	**2j**, 71%
1b, $R^1 = R^2$ = 4-MeO	**2b**, 70%		
1c, $R^1 = R^2$ = 4-F	**2c**, 78%		
1d, $R^1 = R^2$ = 4-Cl	**2d**, 73%		
1e, $R^1 = R^2$ = 4-Br	**2e**, 69%		
1f, $R^1 = R^2$ = 4-CF_3	**2f**, 24%[c]		
1g, $R^1 = R^2$ = 2,4-Me_2	**2g**, 53%	**1k**, R^1 = 4-MeO, R^2 = 4-F	**2k**, 35%[c]
1h, $R^1 = R^2$ = 3,4-Me_2	**2h**, 85%[d]	**1l**, R^1 = 4-EtO, R^2 = 4-CF_3	**2l**, 32%[c]
$R^1 = R^2$ = H, 2-Me, 3-Me	-[e]		
1i, $R^1 = R^2$ = 3,5-Me_2	**2i**, 12%	**1a**	**2m**, 64%[f]

[a] *Reaction condition*: 0.2 mmol **1a**, 0.3 mmol MeOTf, 0.24 mmol TCQ, 1 mL DCE, sealed tube under N_2, 140 °C, 4 h. [b]Isolated yields are shown. [c]2 equiv. of MeOTf, 150 °C, 12 h. [d]Two isomers were observed in 4:1 ratio, the major isomer was shown. [e]No desire products were observed. [f]EtOTf was used.

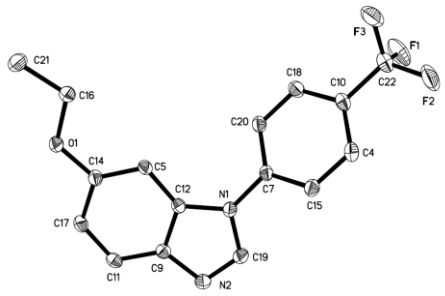
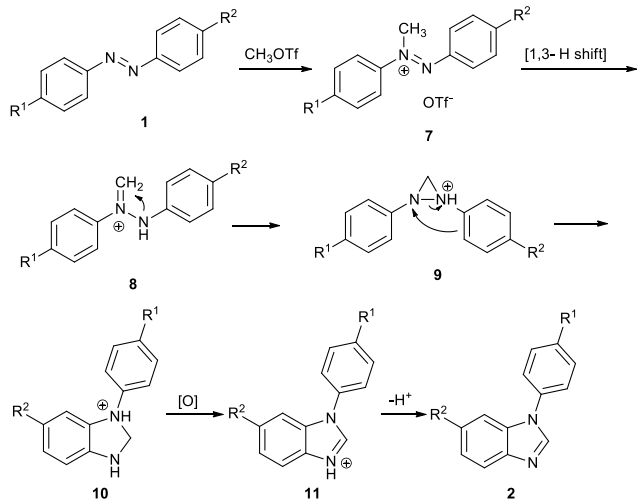


Fig. 2 The X-ray crystal structure of **2l**. Thermal ellipsoids are shown at the 30% probability level; hydrogen atoms have been omitted for clarity.

Ferguson has reported methylation of azo compounds by MeOTf affords diazenium salts under reflux with excess MeOTf as solvent.[8] And diazenium with α-hydrogen can rearrange to the more stable hydrazonium (aminoimmonium) tautomer easily.[9] On the basis of the literature and our results, a plausible mechanism for the reaction of azo compounds with MeOTf was illustrated in Scheme 3. First, methylation of **1** affords diazenium salt **7**, which then tautomerizes to hydrazonium salt **8** *via* [1,3] hydrogen shift.[9a] Cyclization of **8** yields diaziridine **9**, which converts to dihydrobenzoimidazole **10** via *o*-semidine rearrangement.[3d,5a,10] When unsymmetrically azobenzenes are used, the cyclization occurs in the electron-rich phenyl ring. Dihydrobenzoimidazole **10** is then oxidized to protonated benzoimidazole **11** by TCQ or azo compound[11]. Workup of **11** by base affords benzoimidazole **2**.



Scheme 3 Plausible reaction mechanism

In general, transition-metal-mediated N=N bond cleavage involves two steps: 1) formation of diazametallocycles, which are based on donation of electrons from nitrogen to transition metals as well as backdonation of d electrons from transition metals to antibonding orbital of N=N bond; 2) reduction affords imido metal complexes, or rearrangement results *o*-semidine metal complexes. In contrast, utilization of methyl cation, there is one empty orbital and no lone pair, so it can't form diaziridine directly. In our reaction, diaziridine **9** was formed by stepwise [1,3] hydrogen shift and cyclization. Apparently, C-H bond of methyl cation serves as lone pair to form the diaziridine **9**. In other words, in this case, methyl cation could mimic the chemical behavior of transition metals in N=N bond cleavage.

Conclusion

In conclusion, we have developed a new type of N=N bond cleavage reaction with methyl triflate. The methyl carbon atom inserts into the N=N bond to form *N*-arylbenzimidazole. This is the first example N=N bond cleavage by light main group element. Further investigations are still in progress in this area.

Experimental section

General procedures

To a 25 mL tube charged with nitrogen, was added azo compounds **1** (0.2 mmol), TCQ (0.24 mmol), MeOTf (0.3 mmol), DCE 1 mL. The tube was sealed and stirred for 4 h at 140 °C. Removing the solvent of reaction mixture and subsequent purification by column chromatography on silica gel (petroleum ether/ethyl acetate/triethylamine: 1/1/0.05) afforded benzimidazole **2**.

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Notes and references

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† Electronic Supplementary Information (ESI) available: [Experimental procedures, full characterization including ^{1}H NMR and ^{13}C NMR data for all new compounds, copies of spectra for all compounds, and the X-ray data for **2l** and **3a** (CIF)]. See DOI: 10.1039/b000000x/

‡ **3a**: CCDC 978439, **2l**: 978438 .

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