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[2π + 2σ] TYPE CYCLOADDITION REACTIONS OF NAPHTHO[*b*]CYCLOPROPENE WITH IMINE OR CARBONYL DERIVATIVES CONJUGATED WITH HETEROAROMATIC RING TO FORM NAPHTHO[*b*]DIHYDROPYRROLES OR FURANS

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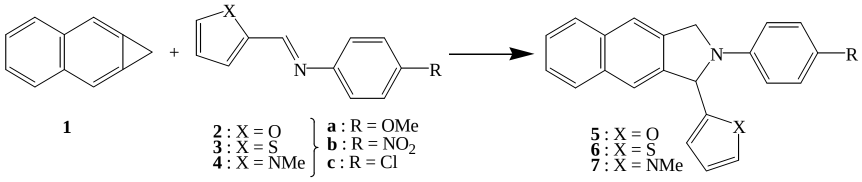
Abstract — Imine derivatives conjugated with heteroaromatic ring such as furan, thiophene or pyrrole reacted with naphtho[*b*]cyclopropene in the presence of silver or ytterbium catalysts. The reactions proceeded *via* [2π + 2σ] type cycloaddition process to give naphtho[*b*]dihydropyrrole derivatives. The yields of the cycloadducts were influenced by the heteroaromatic ring, *i.e.* the furan derivatives gave high yields and the pyrrole derivatives gave low ones. The effects of the catalysts and the solvents were also investigated. The analogous reactions with heterocyclic aldehydes gave naphtho[*b*]dihydrofuran derivatives. Furthermore, a reaction with a hydrazone derivative afforded an open chain type adduct.

Owing to the distorted sp^2 hybridized carbon atoms, the cyclopropene ring fused with aromatic rings of benzocyclopropene or naphtho[*b*]cyclopropene (**1**) are known to be highly reactive.[1] Under the acidic conditions, they easily open the three-membered rings. An existence of two types of paths in cycloaddition reactions has been published. One is a process in which they react as 2π components and the other is a process in which they react as 2σ components.[2] Recently, a possibility of their carbenic behavior was published.[3] Previously, we have investigated on the cycloaddition reactions of these kinds of cyclopropenes,[4] to find the [2π + 2σ], [4π + 2σ] or [8π + 2σ] processes in cycloaddition reactions with nitrones or tropones to form heterocyclic compounds.[2,5] As a series of our researches on the reactivities of cyclopropenes, we investigated reactions of **1** with various imines or aldehydes conjugated with heterocycle (furan, thiophene, and pyrrole) resulted in dependence of the yields upon the heterocycles of the imines. Herein, we will report the results of the reactions.



A benzene solution of **1** and an equimolar amount of *N*-furanylmethylene-*p*-methoxyaniline (**2a**) was stirred at reflux temperature for 3 days. The reaction mixture was chromatographed on silica gel to give a naphtho[*b*]dihydropyrole derivative (**5a**) in 24 % yield together with 13 % yield of the recovery of the starting material (**2a**).[6] The reaction was much improved by an addition of a catalytic amount of $AgBF_4$.[7] For example, when a benzene solution of **1** and an equimolar amount of **2a** containing 3 mol % of $AgBF_4$ was stirred at 0 °C for 0.5 h, the yield of **5a** was promoted to 62 %.

Table 1. Influence of catalysts on the yields of **5a** and **5b**

Compound	Solvent	Temp. (°C)	Time	Additive	Yield (%)	
5a	C_6H_6	80	3 days	—	24	
		0	0.5 h	3 mol %$AgBF_4$	62	(Best result)
		60	3 days	3 mol %$Yb(fod)_3$	9	
5b	$CHCl_3$	60	3 days	—	13	
		60	3 days	3 mol %$Yb(fod)_3$	32	(Best result)

Ytterbium complex was also found to be useful to accelerate the reaction. In fact that the reaction of **1** and **2b** in chloroform under the presence of 3 mol % of $Yb(fod)_3$ at 60 °C for 3days gave **5b** in 32 % yield. The influences of these catalysts under the various reaction conditions were investigated and are shown in Table 1.

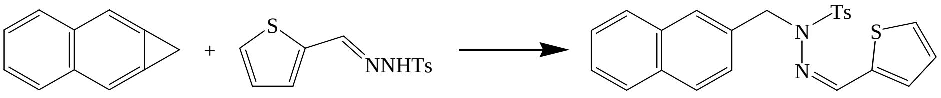
Taking into account the results summarized in Table 1, the reactions in the presence of $AgBF_4$ in benzene at 0 °C and in the presence of $Yb(fod)_3$ at 60 °C were investigated as follows. The reactions with *N*-furanylmethylene-*p*-nitroaniline (**2b**), *N*-thiophenylmethylene-2-aniline (**3**), and *N*-pyrrolylmethylene-2-aniline (**4**) derivatives under the several reaction conditions mentioned above afforded the corresponding cycloadducts, naphtho[*b*]dihydropyrrole derivatives (**5b**, **6**, and **7**, respectively).[9] The results of these reactions are summarized in Table 2.[10]

Table 2. Product yields of reactions of **1** with **2-4**

Solvent	Temp. (^{o}C)	Time	Additive	X	R	Yield (%)
C_6H_6	0	0.5 h	$AgBF_4$	O	OMe	62
					NO_2	30
				S	OMe	14
					NO_2	2
				NMe	OMe	0
					NO_2	0
$CHCl_3$	60	3 days	Yb(fod)$_3$	O	OMe	56
					NO_2	30
				S	OMe	36
					NO_2	31
				NMe	OMe	32
					Cl	3

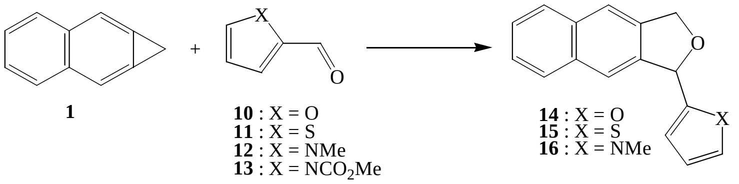
At the same time, the analogous reaction of **1** with hydrazone derivative (**8**) under the presence of $AgBF_4$ in benzene at 0 ^{o}C failed to give any cycloaddition products, but afforded an open chain adduct (**9**) *via* a σ bond rupture in almost a quantitative yield.[11, 12]

The structures of **5**, **6**, and **7** were deduced on the basis of their spectral properties (^{1}H or ^{13}C NMR, IR, and MS spectra). Especially, an absence of any coupling between the methine and the methylene protons in the ^{1}H NMR spectra well supported the structures. The structures of **5**, **6**, **7**, and **9** were finally confirmed by the good coincidences of their physical properties with those of the analogous compounds.[13]

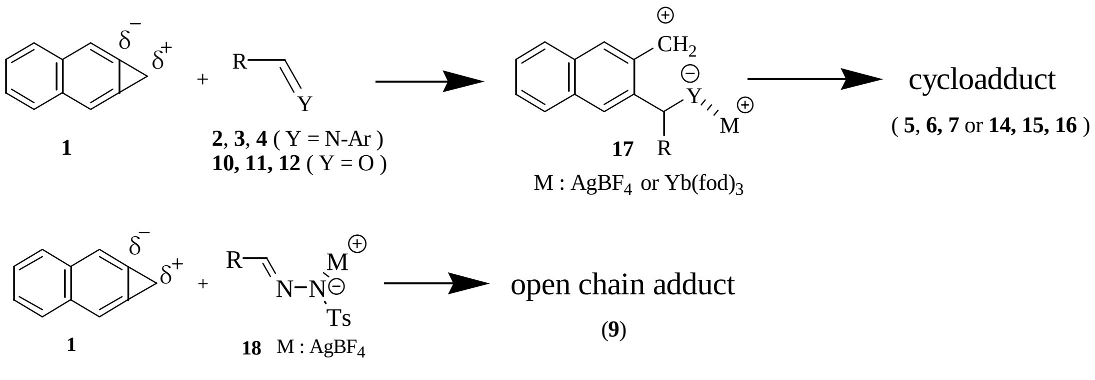


1 **8** **9**

Furthermore, the analogous reactions of **1** with aldehydes conjugated with heterocyclic system were also investigated. The reaction of **1** with an equimolar amount of fulfural (**10**) in chloroform in the presence of 3 mol % of Yb(fod)$_3$ at 60 ^{o}C for 3 days afforded the corresponding cycloadduct, naphtho[*b*]dihydrofuran derivative (**14**), though the yield was not so good (13 %). Similarly, the reactions with thiophenealdehyde (**11**) and *N*-methyl-2-formylpyrrole (**12**) gave the corresponding cycloadducts (**15** and **16** in 7 and 11 % yields, respectively).[14] The *N*-methoxycarbonyl-2-formylpyrrole (**13**) did not afford any cycloadduct.



We speculate these reactions to proceed as follows. The PM3 calculation of **1** revealed that the methylene carbon atom was charged to be positive and the bridgehead carbon atom was charged to negative, respectively.[2, 5, 15] This showed that the bridgehead carbon atoms had a possibility to attack the electron deficient parts of the target molecules. Probably, the imine or carbonyl carbon atoms activated by coordinations with $AgBF_4$ or $Yb(fod)_3$ were attacked by the negatively-charged bridgehead carbon atoms of **1** to form the ionic intermediate (**17**), which then successively cyclized to form the final products. The dependence of the yields upon the heterocycles is elucidated by the reactivities of the imines, which are affected by an electron-donating resonance effect of heteroatoms in the heterocycles (furan < thiophene < pyrrole).



At the same time, the reaction with hydrazone derivative (**8**) is considered to come amid generation of hydrazone anion (**18**) activated by coordination with $AgBF_4$. Nucleophilic attack of the anionic nitrogen atom to the positively charged methylene carbon atom of **1** may afford the final product.

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9. ^{1}H NMR spectral data of the cycloadducts are as follows.

   5a: mp 157.6-158.1 °C (from hexane-ethyl acetate); ^{1}H NMR ($CDCl_3$) δ: 3.75 (s, 3 H), 4.75 (d, 1 H, *J* = 13.5 Hz), 5.08 (d, 1 H, *J* = 13.5 Hz), 6.07 (s, 1 H), 6.25 (m, 1 H), 6.29 (m, 1 H), 6.76 (d, 2 H, *J* = 9.1 Hz), 6.87 (d, 2 H, *J* = 9.1 Hz, m, 1 H), 7.24 (m, 1 H), 7.32-7.47 (m, 2 H), 7.70 (s, 1 H), 7.78-7.85 (m, 3 H).

   5b: mp 133.6-134.4 °C; ^{1}H NMR ($CDCl_3$) δ: 4.89 (d, 1 H, *J* = 14.3 Hz), 5.08 (d, 1 H, *J* = 14.3 Hz), 6.20-6.23 (m, 2 H, s, 1H), 6.68 (d, 2 H, *J* = 9.3 Hz), 7.24 (m, 1 H), 7.39-7.42 (m, 2 H), 7.67 (s, 1 H), 7.74-7.78 (m, 3 H), 8.09 (d, 2 H, *J* = 9.3 Hz).

   6a: mp 146.6-147.8 °C; ^{1}H NMR ($CDCl_3$) δ: 3.74 (s, 3 H), 4.78 (d, 1 H, *J* = 14.2 Hz), 5.15 (d, 1 H, *J* = 14.2 Hz), 6.20 (s, 1 H), 6.75 (d, 2 H, *J* = 8.9 Hz), 6.83 (d, 2 H, *J* = 8.9 Hz), 7.00 (m, 1 H), 7.20 (m, 1 H), 7.25 (m, 1 H), 7.39-7.42 (m, 2 H), 7.67 (s, 1 H), 7.74-7.78 (m, 3 H).

   6b: mp 123.6-124.8 °C; ^{1}H NMR ($CDCl_3$) δ: 5.10 (d, 1 H, *J* = 15.0 Hz), 5.15 (d, 1 H, *J* = 15.0 Hz), 6.45 (s, 1 H), 6.80 (d, 2 H, *J* = 8.7 Hz), 7.00 (m, 1 H), 7.19-7.28 (m, 2 H), 7.40-7.50 (m, 2 H), 7.71 (s, 1 H), 7.78-7.90 (m, 3 H), 8.19 (d, 2 H, *J* = 8.7 Hz).

7a: red oil; ^{1}H NMR (CDCl$_3$) **δ**: 3.11 (s, 3 H), 3.74 (s, 3 H), 4.75 (d, 1 H, *J* = 14.2 Hz), 5.03 (d, 1 H, *J* = 14.2 Hz), 6.12 (m, 1 H), 6.15 (s, 1 H), 6.44 (m, 1 H), 6.47 (m, 1 H), 6.85 (d, 2 H, *J* = 8.5 Hz), 7.18 (d, 2 H, *J* = 8.5 Hz), 7.45-7.83 (m, 6 H).

7c: mp 157.6-158.5 $^{\circ}$C; ^{1}H NMR (CDCl$_3$) **δ**: 3.08 (s, 3 H), 4.82 (d, 1 H, *J* = 13.9 Hz), 5.03 (d, 1 H, *J* = 13.9 Hz), 6.20 (m, 1 H), 6.29 (s, 1 H), 6.65 (m, 1 H), 6.79 (m, 1 H), 6.89 (d, 2 H, *J* = 8.7 Hz), 7.14 (d, 2 H, *J* = 8.7 Hz), 7.45-7.83 (m, 6 H).

10. The reactions with imines possessing electron-withdrawing groups failed to afford any isolable products.

11. ^{1}H NMR spectral data of **9** is as follows.

    mp 123.6-124.8 $^{\circ}$C; ^{1}H NMR (CDCl$_3$) **δ**: 2.45 (s, 3 H), 4.87 (s, 2 H), 6.93 (m, 1 H), 7.03 (m, 1 H), 7.31 (m, 1 H), 7.35 (d, 2 H, *J* = 8.2 Hz), 7.48-7.49 (m, 3 H), 7.73-7.91 (m, 4 H, d, 2 H, *J* = 8.2 Hz).

12. The precedented attack of the imine nitrogen atom is attributed to the higher electron dencity at this nitrogen atom (-0.4378) comparing to that in the imine nitrogen atom (-0.0493).

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14. ^{1}H NMR spectral data of the cycloadducts are as follows.

    14: orange oil; ^{1}H NMR (CDCl$_3$) **δ:** 5.27 (d, 1 H, *J* = 14.9 Hz), 5.39 (d, 1 H, *J* = 14.9 Hz), 6.31 (m, 1 H), 6.34 (m, 1 H), 6.36 (s, 1 H), 7.42 (m, 1 H), 7.43-7.48 (m, 2 H), 7.65 (s, 1 H), 7.73 (s, 1 H), 7.80-7.87 (m, 2 H).

    15: yellow oil; ^{1}H NMR (CDCl$_3$) **δ**: 5.25 (d, 1 H, *J* = 15.1 Hz), 5.41 (d, 1 H, *J* = 15.1 Hz), 6.57 (s, 1 H), 7.04 (m, 1 H), 7.28 (m, 1 H), 7.34 (m, 1 H), 7.40-7.51 (m, 2 H), 7.62 (s, 1 H), 7.73 (s, 1 H), 7.78-7.87 (m, 2 H).

    16: brown oil; ^{1}H NMR (CDCl$_3$) **δ**: 3.53 (s, 3 H), 5.24 (d, 1 H, *J* = 15.0 Hz), 5.28 (d, 1 H, *J* = 15.0 Hz), 6.04 (m, 1 H), 6.07 (m, 1 H), 6.40 (s, 1 H), 6.66 (m, 1 H), 7.45-7.50 (m, 2 H), 7.62 (s, 1 H), 7.72 (s, 1 H), 7.80-7.88 (m, 2 H).

15. The electron densities of **1** were calculated as follows.[2,5]