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Reactions of Arylvinylidenecyclopropanes with Bromine and Iodine

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Abstract: Reactions of arylvinylidenecyclopropanes 1 with equimolar amount of bromine or iodine at low temperature produced the corresponding addition products 2, 3 and 5, 6 in moderate to good yields at -40 °C and -100 °C, respectively. On the other hand, the reactions of 1 with equimolar amount of iodine gave the corresponding iodinated naphthalene derivatives 4 via the corresponding addition products 3 under similar conditions at 25 °C. The further transformation of the addition product 6a has been presented.

Key words: arylvinylidenecyclopropanes, bromine, iodine, addition reaction, iodinated naphthalene derivatives

Thermal and photochemical skeletal conversions of vinylidenecyclopropanes **1** have attracted much attention from mechanistic, theoretical, spectroscopic, and synthetic viewpoints in the past decades.^{1,2} Vinylidenecyclopropanes **1** also undergo a variety of unique addition reactions with electrophiles to give novel products sometimes along with the formation of cyclopropane ring-opened products.³

Previously we reported the reaction of *gem*-aryl disubstituted methylenecyclopropanes (MCPs) and vinylidenecyclopropanes with diaryl diselenide to give either 1,2bis(arylselanyl)-3,3-diarylcyclobut-1-ene, four-membered ring, or the corresponding addition products in the presence of iodosobenzene diacetate [PhI(OAc)₂] in moderate to good yields under mild conditions.^{4a,4b} In addition, we also reported that diarylvinylidenecyclopropanes undergo a novel ring-opening reaction upon treatment with excess iodine or bromine at 0–25 °C in 1,2-dichloroethane to give the corresponding diiodinated or dibrominated naphthalene derivatives in good to high yields within three hours.^{4c}

In this paper, we wish to report the addition reactions of arylvinylidenecyclopropanes 1 with equimolar amount of bromine and iodine to produce either the corresponding addition products 2, 3 and 5, 6 at low temperature or the corresponding iodinated naphthalene derivatives 4 at room temperature in moderate to good yields under mild conditions.

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Using diphenylvinylidenecyclopropane (1a, 0.3 mmol) as substrate, we examined the addition reaction with halogen such as bromine (Br₂) or iodine (I₂) (0.3 mmol) in a variety of solvents at -40 °C.⁵ The corresponding addition product 2a (X = Br) or 3a (X = I) was formed as a sole product with *anti*-configuration rather than the cyclopropane ring-opened product. The results are summarized in Table 1. As can be seen from Table 1, 1,2-dichloroethane (DCE) is the solvent of choice (Table 1, entries 4–7). At low temperature (-40 °C) in DCE, the corresponding addition products 2a and 3a were obtained in higher yields (Table 1, entries 3 and 9). With the addition of water (5.0 equiv), the yield of 2a decreased to 61% under identical conditions, indicating that a cationic process might be involved in this addition reaction (Table 1, entry 4).

Under these optimised reaction conditions, we next examined a variety of vinylidenecyclopropanes **1** with bromine. The results are summarized in Table 2. For symmetrical

Table 1Addition Reaction of 1a (88 mg, 0.3 mmol) with Bromineand Iodine (0.3 mmol) at -40 °C

3a. X = I



			,	
Entry	Solvent	X ₂	Temp. (°C)	Yield of 2a and 3a (%) ^a
1	DCE	Br ₂	0	2a , 58
2	DCE	Br ₂	-10	2a , 62
3	DCE	Br ₂	-40	2a , 70
4	DCE	Br ₂	-40	2a , 61 ^b
5	THF	Br ₂	-40	2a , 63
6	MeCN	Br ₂	-40	2a , 51
7	Toluene	Br ₂	-40	2a , 46
8	DCE	I_2	0	3a , 56
9	DCE	I_2	-40	3a , 81

^a Isolated yields.

^b With the addition of 5.0 equiv of H_2O .

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vinylidenecyclopropanes **1b–e**, the corresponding addition products **2b–e** were obtained in moderate to good yields (Table 2, entries 1–4). In order to confirm further the *anti*-configuration of the addition product, the structure of **2c** was determined by X-ray diffraction (Figure 1).⁶

Table 2Addition Reaction of 1b-e (88 mg, 0.3 mmol) withBromine (0.3 mmol) at -40 °C in DCE

R ¹ R ¹ 1b-e	R^2 + Br ₂ DCE + $-40 \circ C, 6 h$	R^{1} R^{1} R^{1} R^{1} R^{1} R^{1} R^{1}
Entry	1 (R ¹ /R ²)	Yield (%) ^a
1	1b (<i>p</i> -FC ₆ H ₄ /C ₆ H ₅)	2b , 85
2	$1c (Ph/p-MeC_6H_4)$	2c , 61
3	1d (<i>p</i> -ClC ₆ H ₄ /Ph)	2d , 81
4	$1e (Ph/p-MeOC_6H_4)$	2e , 53

^a Isolated yields.



Figure 1 The ORTEP drawing of 2c

On the other hand, in the addition reaction of 1a (0.3 mmol) with iodine (0.3 mmol) under similar conditions, we found that the corresponding addition product 3a is labile at room temperature (25 °C) and it can rearrange to the corresponding iodinated naphthalene derivative 4a in good yield under the reaction conditions at room temperature (25 °C; Scheme 1).



Scheme 1 The addition reaction of diphenylvinylidenecyclopropane (1a) with iodine at -40 °C and then at room temperature (25 °C)

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Under these reaction conditions, we found that the addition reactions of a variety of arylvinylidenecyclopropanes 1 with iodine produced the corresponding iodinated naphthalene derivatives 4 in good yields. The results are shown in Table 3.

Table 3 Addition Reaction of Arylvinylidenecyclopropane 1a-e with Iodine in DCE at -40 °C and then at 25 °C

R ¹ R ¹	$= \begin{array}{c} R^2 \\ + I_2 \\ -40 \ ^{\circ}C, 6 \ h \end{array}$	[3] <u>DCE</u> 25 °C	R	R^{1} R^{2} R^{2} R^{2}
Entry	1 (R ¹ /R ²)	Time (h)	Temp (°C)	Yield (%) ^a 4
1	1a (Ph/Ph)	10	25	4a , 80
2	1b (4-FC ₆ H ₄ /Ph)	30	25	4b , 53
3	1c (Ph/4-MeC ₆ H ₄)	10	25	4c , 72
4	$1d (p-MeOC_6H_4/Ph)$	10	25	4d , 77
5	1e (Ph/4-MeOC ₆ H ₄)	10	25	4e , 82

^a Isolated yields.

The structures of products **2**, **3a**, and **4** were determined by ¹H NMR and ¹³C NMR spectroscopic data and HRMS or microanalyses.⁷

In order to identify the reaction pathway, radical scavengers 2,2,6,6-tetramethyl-1-piperidinyloxy (TEMPO) and 2,6-di-tert-butyl-4-methylphenol (BHT) were added into the reaction solution, respectively. We found that the addition reaction also proceeded smoothly in the presence of these radical scavengers TEMPO and BHT. In addition, with the addition of five equivalents of water, the yield of 2a decreased to 61% (Table 1, entries 3 and 4). Moreover, with the addition of an amino compound such as DBU (10 mol%), 2a was formed in trace. All these results suggest that these above addition reactions proceed via the corresponding cationic intermediates. A plausible reaction mechanism is shown in Scheme 2 on the basis of previous literature and above control experiments. The addition of halogen (X₂) to a double bond of arylvinylidenecyclopropane 1 gives the cationic cyclized intermediate A-1, which is stabilized by a cyclopropane. The backside attack of the formed X^- to the intermediate A-1 produces the anti-addition product 2 or 3. In the case of addition reaction with iodine, the corresponding addition product is labile, which can release one iodine anion to give the corresponding cationic intermediate B-1 at room temperature.8 The intramolecular Friedel-Crafts reaction affords the intermediate C-1, which produces the intermediate d-1 after the proton transfer. This process also can proceed via a concerted 1,3-hydrogen transfer. The reprotonation and aromatization of the intermediate E-1 furnish the iodinated naphthalene derivative 4a.



Scheme 2 A plausible reaction mechanism of arylvinylidenecyclopropanes **1a**–e with halogen

Interestingly, in the reaction of diphenylvinylidenecyclopropane (**1f**), having four methyl groups at the cyclopropane moiety, with halogen Br_2 or I_2 under similar conditions, the corresponding halogenated products **5a** (X = Br) and **6a** (X = I) were obtained in 68% and 46% yields, respectively. When the reaction was carried out at lower temperature (-100 °C) and within short reaction time, **5a** and **6a** were obtained in 88% and 80%, respectively. The results are summarized in Table 4. As can be seen from Table 4, under these reaction conditions the addition reactions of a variety of diarylvinylidenecyclopropanes **1g–j** with bromine and iodine produced the corresponding halogenated alkenes **5** and **6** in good yields in dichloromethane (CH₂Cl₂, Table 4, entries 2–5). For

CH₂Cl₂, -100 °C

unsymmetric arylvinylidenecyclopropane **1j**, the corresponding adduct **5e** was obtained as mixtures of *E*- and *Z*-isomers (Table 4, entry 5).

The mechanism of this addition reaction is shown in Scheme 3 using **1f** as substrate. The addition of halogen (X_2) to a double bond of **1f** produces the corresponding cationic intermediates **A-2** and **B-2**, which give the corresponding ring-opened cationic intermediates **C-2** and **D-2**. Then, elimination of proton takes place to give the corresponding products **5a** and **6a** via cationic intermediates **D-2** (Scheme 3).



Scheme 3 Addition reaction of arylvinylidenecyclopropane 1f with halogen

Moreover, in order to further explore the transformation of **5** and **6**, we employed compound **6a** (0.1 mmol) to the Suzuki type cross-coupling reaction with phenyl boronic acid in the presence of Pd(0) catalyst.⁹ After careful examination of the reaction conditions, we found that using Pd₂(dba)₃ (5 mol%) as catalyst and Cy₃P (10 mol%) as a ligand in DMF (1.0 mL) and water (0.3 mL), the corresponding product **7** was obtained in 68% yield in the presence of Cs₂CO₃ (Scheme 4).¹⁰

 $\label{eq:table4} \begin{array}{c} \mbox{Addition Reaction of Arylvinylidenecyclopropanes 1f-j with iodine in CH_2Cl_2 at -100\ ^{\circ}C \end{array}$

1f–j	5a−e : X = Br 6a−d: X = I				
Entry	$1 (R^{1}/R^{2})$	Time (min)	Yield (%) ^a		
			5 (X = Br)	6 (X = I)	
1	1f (Ph/Ph)	5	5a , 88	6a , 80	
2	$1g(4-MeC_6H_4/4-MeC_6H_4)$	5	5b , 78	6b , 80	
3	1h (4-MeOC ₆ H ₄ /4-MeOC ₆ H ₄)	10	5c , 87	6c , 89	
4	$1i (4-FC_6H_4/4-FC_6H_4)$	5	5d , 95	6d , 79	
5	1j (4-ClC ₆ H ₄ /Ph)	5	5e , 73 ^b		

^a Isolated yields.

^b Mixtures of *E*- and *Z*-isomers (E:Z = 1:1).



Scheme 4 Suzuki type coupling reaction of 6a

In conclusion, we disclosed an interesting addition reaction of arylvinylidenecyclopropanes with halogen to produce the corresponding addition products 2, 3 and 5, 6 or the corresponding iodinated naphthalene derivatives 4 in moderate to good yields under mild conditions.¹¹ The plausible mechanism has been discussed on the basis of control experiments. In addition, the further possible transformation of 6a has been also disclosed. The reason for the bromination and iodination selectively occurred at the cyclopropane-substituted alkene leading to vinyl cyclopropanes is probably due to the stabilization of the corresponding cyclized cationic halogenated intermediate by the cyclopropane. Efforts are underway to elucidate the mechanistic details of this reaction and to disclose the scope and limitations of this transformation. Work along this line is currently in progress.

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- (6) The crystal data of **2c** has been deposited in CCDC with number 273885. Empirical formula: $C_{24}H_{20}Br_2$; formula weight: 468.22; crystal color, habit: colorless, prismatic; crystal dimensions: $0.506 \times 0.367 \times 0.331$ mm; crystal system: triclinic; lattice type: primitive; lattice parameters: a = 8.721 (3)Å, b = 11.157 (3)Å, c = 11.857 (3)Å, a = 109.253 (5)°, $\beta = 106.367$ (5)°, $\gamma = 95.731$ (5)°, V = 1021.1 (5)Å³; space group: P-1; Z = 2; $D_{calcd} = 1.523$ g/ cm³; $F_{000} = 468$; diffractometer: Rigaku AFC7R; residuals:

*R*1 = 0.0739, *wR*2 = 0.1669. A colorless solid, mp 175.1– 176.3 °C. IR (CH₂Cl₂): 3052, 3018, 2960, 2920, 2851, 1613, 1591, 1513, 1488, 1442, 1381, 1261, 1030, 813, 699, 745 cm⁻¹. ¹H NMR (300 MHz, CDCl₃, TMS): δ = 1.22 (1 H, dd, *J*₁ = 8.1 Hz, *J*₂ = 8.1 Hz, CH), 1.70 (1 H, dd, *J*₁ = 8.7 Hz, *J*₂ = 8.7 Hz, CH), 2.40 (3 H, s, Me), 2.90 (1 H, dd, *J*₁ = 8.1 Hz, *J*₂ = 8.1 Hz, CH), 6.94–7.08 (4 H, m, Ar), 7.16–7.26 (5 H, m, Ar), 7.33–7.43 (5 H, m, Ar). MS (EI): *m/z* (%) = 468 (1.75) [M⁺], 389 (13.50), 388 (21.71), 387 (14.75), 309 (15.26), 308 (67.40), 307 (100), 293 (26.93), 292 (32.96), 229 (55.53), 215 (85.84), 189 (18.23), 105 (13.53). HRMS (EI): *m/z* calcd for C₂₄H₂₀Br₂ [M⁺]: 465.9916; found: 465.9932.

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