

Scheme 1. Protocol for the selective synthesis of 1,1-diaryllallenes or 1,3-diaryllallenes by monolithiation of 1-aryl-1-alkynes, transmetalation, and Pd-catalyzed coupling with aryl halides.

coupling with aryl halides leading to 1,1-diaryllallenes (**1**) or 1,3-diaryllallenes (**2**) highly selectively from the same 1-aryl-1-alkynes has been developed (Scheme 1).

Recently, we developed a monolithiation reaction of 1-aryl-1-alkynes with or without the mediation of HgCl_2 .^[2,3] The propargylic/allenylic lithium formed in this reaction undergoes sequential transmetalation and Pd-catalyzed coupling with organic halides leading to alkynes or allenes depending on the structures of the starting materials.^[4] Quite recently, however, we observed that the sequential monolithiation of 1-aryl-1-alkynes beyond 1-aryl-1-propyne, (1-phenyl-1-butyne), the transmetalation, Pd-catalyzed coupling reaction with aryl halides when conducted by different chemists, or even the same chemist at different times, surprisingly gave two products. These products were identified as allenes **1a** and **2a** and formed in very different ratios ranging from 0:100 to 100:0; in other words, in terms of the ratio of **1a** to **2a**, the results were difficult to reproduce (entries 1 and 2, Table 1).

Further investigations showed that with different lithiation reagents, the ratios of **1a** and **2a** are also different, some of the representative results are summarized in Table 1 with the following noteworthy points: (1) No lithiation was observed with *n*BuLi or *t*BuLi at -78°C (entry 7, Table 1);

Table 1: The effect of base on the lithiation of 1-aryl-1-butyne, transmetalation, and the Pd-catalyzed coupling with phenyl iodide.

Entry	$T^{[a]}$	Yield ^[b] (1a / 2a)		
		<i>n</i> BuLi	<i>t</i> BuLi	LDA
1	8°C	100:0–0:100	100:0–0:100	84% ^[c] (0:100)
2	-10°C	100:0–0:100	54% (89:11)	–
3	-20°C	70% (100:0)	28% (93:7)	98% (0:100)
4	-40°C	54% (100:0)	54% (100:0)	96% (19:81)
5	-55°C	–	–	94% (45:55)
6	-65°C	–	–	88% (77:23)
7	-78°C	no lithiation	no lithiation	50% (91:9)

[a] Lithiation temperature. [b] NMR yield determined with CH_2Br_2 as the internal standard. [c] Yield of the isolated product.

Li Reactions in Organic Synthesis

A 1,3-Lithium Shift of Propargylic/Allenlyc Lithium and the Subsequent Transmetalation Coupling Reaction with Aryl Halides**

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Selective synthesis has been a formidable challenge in organic synthesis, especially controlled highly selective synthesis beginning from the same starting materials.^[1] Herein, we report a novel clean 1,3-lithium shift reaction of propargylic/allenylic lithium (Scheme 1). Based on this observation, the corresponding sequential transmetalation and Pd-catalyzed

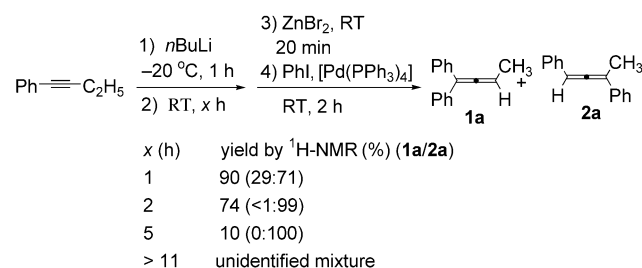
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(2) Lithiation with LDA at -78°C followed by transmetalation and coupling afforded **1a** and **2a** in 50% yield with a ratio of 91:9 (entry 7, Table 1). Lithiation with LDA at a higher temperature favors the formation of **2a**; (3) lithiation with *n*BuLi or *t*BuLi at -20°C or -40°C led to the highly selective or exclusive formation of the nonisomerized product **1a** (entries 3 and 4, Table 1). These facts indicate that the temperature and amine may be the factors that control the isomerization of 1-aryl-1-alkyn-3-yl or 1-aryl-1,2-alkadien-1-yl lithium to 1-aryl-2-alkyn-1-yl or 1-aryl-1,2-alkadien-3-yl lithium, respectively (Scheme 1).

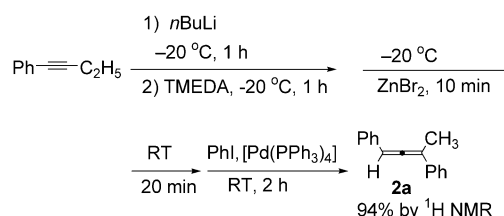
In fact, it was observed that when the lithiation of 1-phenyl-1-butyne was conducted at -20°C for 1 h then at room temperature for 2 h, instead of 1,1-diphenyl-1,2-butadiene (**1a**), the sequential reaction afforded 1,3-diphenyl-1,2-butadiene (**2a**) in 74% yield (Scheme 2). With a longer



Scheme 2. Different lithiation conditions gave different ratios of **1a**/ **2a**.

reaction time for the lithiation at room temperature, the yields of **1a** and **2a** decreased dramatically. When the lithiation was performed at -20°C for 1 h followed by the addition of *N,N,N',N'*-tetramethyl ethylene diamine (TMEDA) at -20°C , the same sequential reaction also afforded the isomerized product 1,3-diphenyl-1,2-butadiene (**2a**) in 94% yield, thus indicating an interesting effect of amine on the 1,3-lithium shift (Scheme 3).

Through trial and error, we were happy to identify two suitable sets of reaction conditions: A) lithiation at -20°C with *n*BuLi for 1 h followed by transmetalation (ZnBr_2 was added at -20°C followed by stirring at room temperature) and coupling at room temperature for the selective formation of 1,1-diaryllallenes; B) lithiation at room temperature with LDA for 1 h followed by transmetalation and coupling at room temperature for the selective formation of 1,3-diaryllallenes. Under conditions A and B, the results can be easily reproduced. Some typical results are presented in Table 2, which indicates that: 1) the reaction is general for differently substituted 1-aryl-1-alkynes/aryl halides; 2) the regioselectivity for the formation of 1,1-diaryllallenes and 1,3-diaryllallenes is excellent.



Scheme 3. The effect of TMEDA on the 1,3-lithium shift.

In conclusion, we have observed a clean and complete 1,3-lithium shift reaction of 1-aryl-1-alkyn-3-yl or 1-aryl-1,2-alkadien-1-yl lithium leading to 1-aryl-1,2-alkadien-3-yl or 1-aryl-2-alkyn-1-yl lithium, respectively. Although this kind of 1,3-metal shift has been observed,^[5–7] the present protocol provides a clear-cut control of the lithiation as well as the isomerization. Under conditions A and B, 1,1-diaryllallenes and 1,3-diaryllallenes, respectively, can be prepared starting from the same alkynes. Although the mechanism of 1,3-lithium shift is not clear, this work may open up a new area for the study and control of 1,3-metal shifts in propargyl/allenylic species. Further investigations in this area are continuing in our laboratory.

Experimental Section

Typical procedure (conditions A): *n*BuLi (0.45 mL, 1.6 M in hexanes, 0.72 mmol) was added to a solution of 1-phenyl-1-butyne (78 mg, 0.6 mmol) in THF (3 mL) in a dry Schlenk tube at -20°C under N_2 . The reaction mixture was stirred at -20°C for 1 h, then a solution of dry ZnBr_2 (275 mg, 1.2 mmol) in THF (4 mL) was added. After a further 10 min at this temperature the reaction mixture was warmed up to room temperature and kept there for 20 min. $[\text{Pd}(\text{PPh}_3)_4]$ (35 mg, 5 mol%) and iodobenzene (83 μL , 0.72 mmol) were subsequently added, and the resulting mixture was stirred at room

Table 2: Reaction under conditions A (*n*BuLi) and B (LDA)

$\text{Ar}^1-\text{C}\equiv\text{CH}_2\text{R} \xrightarrow[\text{ZnBr}_2]{\text{Base, Temp.}} \xrightarrow[\text{Ar}^2\text{I}]{[\text{Pd}(\text{PPh}_3)_4]} \begin{matrix} \text{Ar}^1 & \text{R} \\ \diagdown & / \\ \text{C} & = & \text{C} \\ / & \diagdown \\ \text{Ar}^2 & \text{H} \end{matrix} \text{1} + \begin{matrix} \text{Ar}^1 & \text{R} \\ \diagdown & / \\ \text{C} & = & \text{C} \\ / & \diagdown \\ \text{H} & \text{Ar}^2 \end{matrix} \text{2}$						
Entry (1/2)	Ar^1	CH_2R	Ar^2I	Base	T [$^{\circ}\text{C}$]	Yield [%] ^[a]
1	Ph	C_2H_5	$\text{C}_6\text{H}_5\text{I}$	<i>n</i> BuLi	-20	55 (1a:2a = 100:0)
2	Ph	C_2H_5	$\text{C}_6\text{H}_5\text{I}$	LDA	8	84 (1a:2a = 0:100)
3	Ph	C_4H_9	$\text{C}_6\text{H}_5\text{I}$	<i>n</i> BuLi	-20	71 (1b:2b = 99:1)
4	Ph	C_4H_9	$\text{C}_6\text{H}_5\text{I}$	LDA	10	89 (1b:2b = 0:100)
5	Ph	C_4H_9	<i>p</i> -MeC ₆ H ₄ I	<i>n</i> BuLi	-20	79 (1c:2c = 99:1)
6	Ph	C_4H_9	<i>p</i> -MeC ₆ H ₄ I	LDA	20	99 (1c:2c = 0:100)
7	Ph	C_4H_9	$\alpha\text{-C}_{10}\text{H}_8\text{I}$	<i>n</i> BuLi	-20	63 (1d:2d = 100:0)
8	Ph	C_4H_9	$\alpha\text{-C}_{10}\text{H}_8\text{I}$	LDA	20	56 (1d:2d = 0:100)
9	Ph	C_4H_9	<i>p</i> -MeOC ₆ H ₄ I	<i>n</i> BuLi	-20	74 (1e:2e = 98:2)
10	Ph	C_4H_9	<i>p</i> -MeOC ₆ H ₄ I	LDA	30	83 (1e:2e = 0:100)
11	Ph	C_4H_9	<i>p</i> -MeO ₂ CC ₆ H ₄ I	<i>n</i> BuLi	-20	93 (1f:2f = 100:0)
12	Ph	C_4H_9	<i>p</i> -MeO ₂ CC ₆ H ₄ I	LDA	19	71 (1f:2f = 0:100)
13	Ph	C_3H_7	$\text{C}_6\text{H}_5\text{I}$	<i>n</i> BuLi	-20	76 (1g:2g = 100:0)
14	Ph	C_3H_7	$\text{C}_6\text{H}_5\text{I}$	LDA	11	96 ^[b] (1g:2g = 0:100)
15	<i>p</i> -PhC ₆ H ₄	C_3H_7	$\text{C}_6\text{H}_5\text{I}$	<i>n</i> BuLi	-20	77 (1h:2h = 100:0)
16	<i>p</i> -PhC ₆ H ₄	C_3H_7	$\text{C}_6\text{H}_5\text{I}$	LDA	18	72 (1h:2h = 0:100)

[a] Yield of isolated products with the ratios determined by 300 MHz $^1\text{H NMR}$ analysis. [b] NMR yield determined with CH_2Br_2 as the internal standard.

temperature. After the reaction was complete, as monitored by TLC (eluent: petroleum ether, 60–90 °C), it was quenched with saturated NH_4Cl and extracted with ether. The product solution was dried over MgSO_4 , the solvent was removed by rotary evaporation, and the crude product was purified by flash chromatography on silica gel (petroleum ether) to afford **1a**^[8] (68 mg, 55 %) as a liquid. ^1H NMR (CDCl_3 , 300 MHz): δ = 7.43–7.25 (m, 10H), 5.72 (q, J = 7.1 Hz, 1H), 1.89 ppm (d, J = 7.1 Hz, 3H); ^{13}C NMR (CDCl_3 , 75.4 MHz): δ = 206.32, 137.24, 128.42, 128.28, 126.98, 109.18, 88.85, 14.33 ppm; MS (70 eV): m/z (%): 206 (84.30) [M^+], 191 (100) [$M^+ - \text{CH}_3$]; IR (neat): $\tilde{\nu}$ = 1943 cm^{-1} ; HRMS calcd for $\text{C}_{16}\text{H}_{14}$ [M^+]: 206.10955, found: 206.10914.

Typical procedure (conditions B): LDA (0.4 mL, 2.0 M in THF/ethylbenzene/pentane, 0.8 mmol) was added to a solution of 1-phenyl-1-butyne (58 mg, 0.45 mmol) in THF (3 mL) in a dry Schlenk tube at room temperature under N_2 . After the solution had been stirred for 1 h at room temperature, a solution of dry ZnBr_2 (499 mg, 2.22 mmol) in THF (4 mL) was added. After a further 25 min at this temperature, $[\text{Pd}(\text{PPh}_3)_4]$ (22 mg, 5 mol %) and iodobenzene (42 μL , 0.38 mmol) were added. After the reaction was complete as monitored by TLC (eluent: petroleum ether, 60–90 °C), it was quenched with saturated NH_4Cl and extracted with ether. The resulting solution was dried over MgSO_4 , the solvent was removed by rotary evaporation, and the crude product was purified by flash chromatography on silica gel (petroleum ether) to afford **1b**^[9] (65 mg, 84 %) as a liquid. ^1H NMR (CDCl_3 , 300 MHz): δ = 7.53–7.47 (m, 2H), 7.40–7.20 (m, 8H), 6.50 (q, J = 2.7 Hz, 1H), 2.25 ppm (d, J = 2.7 Hz, 3H); ^{13}C NMR (CDCl_3 , 75.4 MHz): δ = 206.77, 136.23, 134.44, 128.67, 128.43, 127.01, 126.99, 126.85, 125.78, 104.48, 96.56, 16.75 ppm; MS (70 eV): m/z (%): 206 (79.98) [M^+], 191 (100) [$M^+ - \text{CH}_3$]; IR (neat): $\tilde{\nu}$ = 1936 cm^{-1} .

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