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Regular Paper

Simple and efficient copper-catalyzed synthesis of symmetrical diaryl selenides from triarylbismuthanes and selenium under aerobic conditions

Mio Matsumura,^a Hanae Kumagai,^a Yuki Murata,^a Naoki Kakusawa,^b Shuji Yasuike^{a,*}

^a School of Pharmaceutical Sciences, Aichi Gakuin University, 1-100 Kusumoto-cho, Chikusa-ku, Nagoya 464-8650, Japan

^b Faculty of Pharmaceutical Sciences, Hokuriku University, Ho-3 Kanagawa-machi, Kanazawa 920-1181, Japan

*Corresponding authors.

Address: School of Pharmaceutical Sciences, Aichi Gakuin University, 1-100 Kusumoto-cho, Chikusa-ku, Nagoya 464-8650, Japan

Tel: +81-52-757-6774

E-mail address: s-yasuik@dpc.agu.ac.jp (S. Yasuike)

ABSTRACT

Symmetrical diaryl selenides were synthesized in moderate-to-excellent yields by Cu-catalyzed C(aryl)–Se bond formation followed by the reaction of triarylbismuthanes with elemental Se in the presence of $Cu(OAc)_2$ and 1,10-phenanthroline (10 mol%) under aerobic conditions. This reaction proceeded efficiently: All the aryl groups on Bi were transferred to the coupling products.

Keywords: Triarylbisumthane Selenium Diarylselenide Copper catalyst Se-arylation

Highlights:

Cu-catalyzed reaction of Se with Ar₃Bi under aerobic conditions without an additive afforded symmetrical diaryl selenides.

All the three aryl groups on Bi in Ar₃Bi were transferred to the coupling products.

Symmetrical diaryl selenides were obtained from diverse Ar₃Bi in good-to-excellent yields.

1. Introduction

Organoselenium compounds are important reagents in organic synthesis and biology [1-8]. For example, symmetrical diaryl selenides (Ar-Se-Ar) have attracted much attention in the last two decades, because these exhibit wide biological activity such as antitumor and antioxidant activities (Fig. 1.) [9-11]. The transition-metal-catalyzed C(aryl)-Se bond formation is one of the most practical method in modern organic synthesis [3, 12-16]. Various metals including Pd, Ni, Fe and Cu have been used to catalyze the reactions of aryl donors with a Se source. Cu-catalyzed cross-coupling reactions are efficient for the synthesis of diaryl selenide [12-15]. Among these, the reactions of diaryl diselenides with aryl halides [16-25] or boronic acids [26-32] were known as the synthesis of symmetrical diaryl selenides. However, diaryl diselenides are not always commercially available and require complicated preparation steps. Therefore, several methods have been reported for the synthesis of symmetrical diaryl selenides using the following combination of aryl substrates with a Se source: (1) aryl halides and Se [33-36], (2) aryl halides and potassium selenocyanate [37, 38], (3) boronic acids and Se [39, 40], and (4) boronic acids and selenourea [41]. However, most of these reactions require a base and/or an inorganic reagent as the additive. Recently, Yu and co-workers reported the synthesis of symmetrical diaryl selenides by the cross-coupling of arylboronic acids with Se powder without an additive in the presence of pyridine as a co-solvent under inert atmosphere [40].

Fig. 1.

On the other hand, organobismuth compounds are usually nontoxic, environmentally benign, and potentially useful as synthetic reagents [42-45]. Two methods for the synthesis of symmetrical diaryl selenides using triarylbismuthanes (Ar₃Bi) had been reported. Arnauld et al. reported the reaction of an excess amount of Se powder (5 eq) with Ar₃Bi at high temperature (170 °C) [46]. Recently, Ogawa et al. have developed the photoinduced reaction of diphenyl diselenides with Ph₃Bi affording diphenyl selenides; however, an excess amount of the Bi agents bearing three aryl groups on Bi was

required for the reaction [47]. Recently, we reported the Cu-catalyzed synthesis of unsymmetrical diaryl sulfides and selenides (Ar–S–Ar', and Ar–Se–Ar') involving C(aryl)-S and C(aryl)-Se bond formations by the reactions of diaryl disulfides (Ar'–S–S–Ar') and diselenides (Ar'–Se–Se–Ar') with Ar₃Bi under aerobic conditions [48, 49]. All the three aryl groups on the Bi reagent and both the sulfanyl and selanyl groups of the diaryl disulfide and diselenide participated in this reaction. As a continuation of our studies on C(aryl)-heteroatom bond formation, we now report an atom-economic and simple Cu-catalyzed procedure for the synthesis of symmetrical diaryl selenides from Se powder and Ar₃Bi without the use of an additive under aerobic conditions.

2. Results and discussion

First, the optimal experimental conditions were determined for the cross-coupling of chalcogen powder (S, Se, Te) with organobismuth and organoantimony compounds such as Ph₃Bi (1a), Ph₃BiCl₂ (2), Ph₃BiF₂ (3), Ph₃Bi(OAc)₂ (4), Ph₃Sb (5), Ph₃SbCl₂ (6), Ph₃SbF₂ (7), and Ph₃Sb(OAc)₂ (8). Table 1 shows the results of the screening of chalcogens, aryl substrates, catalysts, ligands, and solvents. The cross-coupling reactions of Ar₃Bi with diaryl disulfides using CuOAc and 1,10-phenanthroline as the catalytic system under aerobic conditions in DMSO afforded the corresponding unsymmetrical diaryl sulfides [48]. We first performed the reaction between chalcogen powder with Ph₃Bi (1a) under the optimal conditions reported by us previously [Cu(OAc) (10 mol%), 1,10-phenanthroline (10 mol%), DMSO, 100 °C] (entries 1-3). The expected coupling compound **9b** was obtained in a high yield (81%) when Se was employed as the chalcogen (entry 2). In this reaction, all the three phenyl groups on Bi participated in the C(Ar)–Se bond formation. On the other hand, S and Te were less reactive toward this reaction (entries 1, 3). A complex mixture was obtained in the reaction of 1a with Te. The reactions of Se with organobismuth compounds such as 1a, 2, 3 and 4 were performed under the same conditions to compare their reactivity (entries 2, 4-6). The results show that Ph₃Bi (1a) was the best aryl donor. When pentavalent compounds such as Ph_3BiCl_2 (2) and $Ph_3Bi(OAc)_2$ (4) were employed in this reaction, diphenyl diselenide (10b) was formed as the major product. When organoantimony reagents (5-8) were used instead of the Bi

reagents, the reaction afforded 9b in <8% yield (entries 7-10). Next, several available Cu catalysts were screened in the reaction of 1a with Se (entries 2, 11-18). $Cu(OAc)_2$ was the best catalyst for this reaction in terms of the yield (87%) of the expected product 9b and reaction time (3 h), and the yield of byproduct 10b was < 1%. Various ligands (L1-6) were screened (entries 15, 20-24). The results show that 1,10-phenanthroline (L1) was the most effective. The screening of solvents showed that the reaction proceeded efficiently in DMSO (87%), DMF (84%), and CH₃CN (60%), whereas N-methylpyrrolidone, toluene, 1,4-dioxane, and 1,2-DCE were inefficient (entries 15, 26-31). A significant decrease in the yield of product 9b under Ar atmosphere indicated that the presence of O_2 in the reaction medium was essential for the progress of the reaction (entry 32). The progressive addition of pure O₂ shortened the reaction time (entry 33). The reactions under aerobic conditions were simple and easy to operate. The reaction was sensitive to catalyst loading, as a decrease in the loading of Cu(OAc)₂ from 10 mol% to 5 mol% significantly reduced the yield of 9b (62%, 24 h, entry 34). When the loading of Se (3 eq) was increased, this reaction afforded a mixture of 9b and 10b, and diphenyl diselenide (10b) was obtained as the major product (entry 35). Thus, the best reaction condition was determined to be as follows: Ph₃Bi (1a) was treated with 1.5 equiv. Se powder using 10 mol% Cu(OAc)₂ and 1,10-phenanthroline as the catalytic system in DMSO at 100 °C without the use of any base and/or inorganic reagent under aerobic conditions.

Table 1

To demonstrate the efficiency and generality of the above-mentioned protocol, the reactions of various Ar_3Bi compounds (**1a-1**) and Se powder were investigated under the optimized reaction conditions. The results are shown in Table 2. The yields of the coupling products are based on all the three aryl groups on the Bi compounds used in the reaction. The reaction of Ar_3Bi compounds (**1b-i**) bearing electron-donating and electron-withdrawing substituents on the aromatic ring afforded the corresponding symmetrical diaryl selenides (**11-18**) in good-to-excellent yields. The electronic nature (electron-rich or electron-poor) of the substituents in the 4-substituted Ar_3Bi did not affect the

outcome of the reaction (entries 1-6). Sterically hindered *ortho*-substituted Bi compounds were also coupled with Se, affording the corresponding diaryl selenides (**16-19**) even though a prolonged reaction was required for the methyl-substituted series of Bi reagents (entries 7-10). Ar₃Bi (**1i**) bearing a CH₂NH₂ group in the *ortho*-position has a hypervalent bond between the N and Bi atoms [50]. These hypervalent compounds showed a significant increase in the reactivity of the aryl group toward the transition-metal-catalyzed cross-coupling reactions. For example, Tanaka et al. reported that hypervalent Ar₃Bi compounds, 6-*tert*-butyl-5,6,7,12-tetrahydrodibenz[*c*,*f*][**1**,5]azabismocines, are useful arylating agents for the synthesis of biaryl derivatives using Pd-catalyzed cross-coupling reactions [51]. The reaction time of Ar₃Bi (**1i**) bearing a CH₂NH₂ group in the *ortho*-position was shorter than those of the methyl-substituted compounds **1g** and **1h** (entry 9). This reaction also showed the effect of hypervalent compound. Moreover, the reactions of heterocyclic Bi reagents afforded the corresponding selenides (**20**, **21**) (entries 11, 12).

Table 2

To investigate the reaction mechanism, we have explored the possible reaction pathway. When the reaction of Ph₃Bi with elemental Se monitored by using GC, the generation of diphenyl diselenide (**10b**) as well as diphenyl selenide (**9b**) was confirmed in the reaction process (Fig. 2.). The reaction of Ph₃Bi with diphenyl diselenide (**10b**) in the presence of Cu(OAc)₂ (10 mol%) and 1,10-phenanthroline (10 mol%) under aerobic condition led to the formation of diphenyl selenide (**9b**) in 89% yield. Therefore, a similar mechanism is possible as those proposed for the Chan-Lam *S*-arylation with arylboronic acids by Yu [40], and *Se*-arylation of aryl iodides with Se by Jin [36], and reaction of diaryl disulfides and diselenide with Ar₃Bi by us [48, 49]. Fig. 3 shows the possible mechanism for the synthesis of symmetrical diaryl selenides from Ar₃Bi and Se. The first step of the reaction involves the generation of a catalytically active (μ -hydroxide)Cu(II) complex (**A**) from CuOAc or Cu(OAc)₂, 1,10-phenanthroline, molecular oxygen and moisture in air and/or solvent [52]. The transmetallation between Ar₃Bi and **A** forms intermediate (**B**); subsequent oxidative addition of

Se to **B** gives Cu(III) intermediate (**C**). The reductive elimination from **C** could affords desired aryl selenide anion (Ar–Se⁻) and Cu(0). The aryl selenide anion is oxidized with H₂O and aerobic oxygen, affording diaryl diselenide (**D**). Cu(I) or (II) may be regenerated by air oxidation. Next, the ligand-exchange reaction of regenerated **A** with the arylselanyl moiety of diaryl diselenide (**D**) forms the intermediate (**E**); the subsequent oxidative addition of an aryl moiety of Ar₃Bi to **E** affords Cu(III) intermediate (**F**). The reductive elimination of coupling product (**G**) from intermediate (**F**) regenerates the Cu catalyst. Another catalytic cycle may be possible: The transmetallation of **A** with an aryl moiety of Ar₃Bi affords **B**, and oxidative addition of the selanyl moiety of diaryl diselenide (**D**) gives Cu(III) intermediate (**F**), which probably undergoes reductive elimination to afford the asymmetric diaryl selenide.

Fig. 2 and 3.

3. Conclusion

Symmetrical diaryl selenides were synthesized from Se powder and Ar_3Bi without an additive under aerobic conditions. Under mild conditions, all the three aryl groups on the Bi reagent participated in the reaction, and the reaction of bismuthanes bearing various functional groups afforded the corresponding cross-coupling products in satisfactory yields. The studies on the mechanism of this reaction and reactions of Ar_3Bi with other coupling partners are underway.

4. Experimental

4.1. General

Melting points measurements were conducted on a Yanagimoto micro melting point hot-stage apparatus (MP–S3) and reported as uncorrected values. ¹H-NMR (TMS: δ : 0.00 as an internal standard), ¹³C-NMR (CDCl₃: δ : 77.00 as an internal standard) and spectra were recorded on JEOL JNM–AL400 (400 MHz and 100 MHz respectively) spectrometers in CDCl₃. Mass spectra were

obtained on a JEOL JMP-DX300 instrument (70 eV, 300 μ A). All chromatographic separations were accomplished with Silica Gel 60N (Kanto Chemical Co., Inc.). Thin-layer chromatography (TLC) was performed with Macherey-Nagel Pre-coated TLC plates Sil G25 UV₂₅₄. Terminal alkynes **9** were purchased from Wako Pure Chemical Industries Ltd. and TCI Fine Chemicals, Japan. Triphenylbismuthane (**1a**) and tris(*o*-tolyl)bismuthane (**1g**) were purchased from TCI Fine Chemicals, Japan, and other triarylbismuthanes such as **1b-d** [53], **1e** [54], **1f** [46], **1h** [55], **1i** [50], **1j** [53], **1k** [56] and **1l** [49] were prepared according to the reported procedures.

4.2. Reaction of Ar₃Bi with Se

A mixture of Ar₃Bi **1** (0.5 mmol), Se powder (0.75 mmol), Cu(OAc)₂ (0.05 mmol), and 1,10-phenanthroline (0.05 mmol) in DMSO (5 mL) was heated at 100 °C under air atmosphere for the desired time (Table 2) until the complete consumption of the starting material on TLC. After diluting with CH₂Cl₂ (50 mL) and water (30 mL), the reaction mixture was separated and the aqueous layer was extracted with CH₂Cl₂ (30 x 2 mL). The combined organic layer was washed with 5% aqueous ammonia and water, dried over anhydrous MgSO₄ and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel using a mixture of hexane/CH₂Cl₂ as the eluent, affording diaryl selenides **9b** and **11-20**. Compound (**21**) was purified by column chromatography on aluminum oxide with hexane/Et₂O. The products **9b** and **11-20** were confirmed by comparison of their NMR data and mass spectra with the literature data.

Diphenyl selenide (**9b**) [31, 35]: Pale yellow oil. ¹H NMR (400 MHz, CDCl₃) δ: 7.20-7.28 (6H, m, Ar-H), 7.40-7.49 (4H, m, Ar-H); ¹³C NMR (100 MHz, CDCl₃) δ: 127.1, 129.2, 131.3, 132.8. LR-MS m/z: 234 (M⁺).

Bis(4-*methoxyphenyl*) *selenide* (**11**) [31, 35]: Colorless prisms. mp 55-57 °C (from hexane). ¹H NMR (400 MHz, CDCl₃) δ : 3.77 (6H, s, OCH₃), 6.80 (4H, d, J = 8.8 Hz, Ar-H), 7.39 (4H, d, J = 8.8 Hz, Ar-H); ¹³C NMR (100 MHz, CDCl₃) δ : 55.2, 114.9, 122.0, 134.5, 159.2. LR-MS m/z: 294 (M⁺). *Bis*(*p*-*tolyl*) *selenide* (**12**) [31, 35]: Colorless prisms. mp 68-70 °C (from hexane). ¹H NMR (400 MHz, CDCl₃) δ : 2.32 (6H, s, CH₃), 7.07 (4H, d, J = 7.8 Hz, Ar-H), 7.35 (4H, d, J = 7.8 Hz, Ar-H);

¹³C NMR (100 MHz, CDCl₃) δ: 21.1, 127.7, 130.1, 133.0, 137.2. LR-MS m/z: 262 (M⁺).

Bis(4-chlorophenyl) selenide (**13**) [35]: Colorless flakes. mp 95-97 °C (from hexane - CH₂Cl₂). ¹H NMR (400 MHz, CDCl₃) δ : 7.24 (4H, d, J = 8.3 Hz, Ar-H), 7.37 (4H, d, J = 8.3 Hz, Ar-H); ¹³C NMR (100 MHz, CDCl₃) δ : 129.0, 129.6, 133.9, 134.3. LR-MS m/z: 302 (M⁺).

Bis(4-ethoxycarbonylphenyl) selenide (**14**) [57]: Colorless prisms. mp 38-41 °C (from hexane). ¹H NMR (400 MHz, CDCl₃) δ : 1.39 (6H, t, J = 7.1 Hz, CH₃), 4.38 (4H, t, J = 7.1 Hz, CH₂), 7.50 (4H, d, J = 8.3 Hz, Ar-H), 7.94 (4H, d, J = 8.3 Hz, Ar-H); ¹³C NMR (100 MHz, CDCl₃) δ : 14.3, 61.1, 129.7, 130.4, 132.5, 136.7, 166.1. IR (KBr) cm⁻¹: 1712. LR-MS m/z: 378 (M⁺).

Bis(4-*trifluoromethylphenyl*) *selenide* (**15**) [35]: Colorless oil. ¹H NMR (400 MHz, CDCl₃) δ: 7.54 (4H, d, J = 9.3 Hz, Ar-H), 7.57 (4H, d, J = 9.3 Hz, Ar-H); ¹³C NMR (100 MHz, CDCl₃) δ: 123.9 (q, $J_{c, f} = 272$ Hz), 126.3 (q, $J_{c, f} = 3.9$ Hz), 130.0 (q, $J_{c, f} = 32.3$ Hz), 133.1, 135.2. LR-MS m/z: 370 (M⁺). *Bis*(*o*-*tolyl*) *selenide* (**16**) [35]: Colorless flakes. mp 57-60 °C (from hexane). ¹H NMR (400 MHz, CDCl₃) δ: 2.39 (6H, s, CH₃), 7.04 (2H, t, J = 7.4 Hz, Ar-H), 7.16-7.24 (6H, m, Ar-H); ¹³C NMR (100 MHz, CDCl₃) δ: 22.2, 126.8, 127.6, 130.2, 131.3, 133.2, 139.8. LR-MS m/z: 262 (M⁺).

Bis(2,4,6-*mesityl*) *selenide* (**17**) [57]: Colorless prisms. mp 104-105 °C (from hexane). ¹H NMR (400 MHz, CDCl₃) δ: 2.23 (6H, s, CH₃), 2.24 (12H, s, CH₃), 6.83 (4H, s, Ar-H); ¹³C NMR (100 MHz, CDCl₃) δ: 20.8, 23.5, 128.9, 129.4, 136.9, 141.3. LR-MS m/z: 318 (M⁺).

Bis[2-(*N*, *N*-*dimethylamino*)*benzyl*] *selenide* (**18**) [58]: Colorless prisms. mp 63-65 °C (from hexane). ¹H NMR (400 MHz, CDCl₃) δ: 2.25 (12H, s, CH₃), 3.56 (4H, s, CH₂), 7.08 (2H, dt, *J* = 7.8, 1.5 Hz, Ar-H), 7.22 (2H, dt, *J* = 7.8, 1.5 Hz, Ar-H), 7.26 (2H, dd, *J* = 7.8, 1.5 Hz, Ar-H), 7.39 (2H, d, *J* = 7.8 Hz, Ar-H); ¹³C NMR (100 MHz, CDCl₃) δ: 44.9, 63.9, 127.0, 127.8, 129.8, 134.2, 134.4, 140.3. LR-MS m/z: 348 (M⁺).

Bis(*1-naphthyl*) *selenide* (**19**) [31, 35]: Colorless prisms. mp 103-105 °C (from hexane - CH₂Cl₂). ¹H NMR (400 MHz, CDCl₃) δ: 7.27 (2H, t, *J* = 7.3 Hz, Ar-H), 7.48 (2H, dd, *J* = 7.3, 1.5 Hz, Ar-H), 7.50-7.54 (4H, m, Ar-H), 7.78 (2H, d, *J* = 8.3 Hz, Ar-H), 7.83-7.88 (2H, m, Ar-H), 8.32-8.36 (2H, m, Ar-H); ¹³C NMR (100 MHz, CDCl₃) δ: 126.1, 126.3, 126.8, 127.1, 128.4, 128.6, 129.8, 137.2, 133.6, 134.1. LR-MS m/z: 334 (M⁺).

Bis(2-*thienyl*) *selenide* (**20**) [41]: Colorless oil. ¹H NMR (400 MHz, CDCl₃) δ : 6.95 (2H, dd, J = 3.4, 5.4 Hz, Ar-H), 7.27 (2H, d, J = 3.4 Hz, Ar-H), 7.35 (2H, d, J = 5.4 Hz, Ar-H); ¹³C NMR (100 MHz, CDCl₃) δ : 126.3, 127.9, 130.9, 134.7. LR-MS m/z: 246 (M⁺).

Bis(2-*benzothienyl*) *selenide* (**21**): Yellow prisms. mp 129-131 °C (from hexane - CH₂Cl₂). ¹H NMR (400 MHz, CDCl₃) δ : 7.28 (2H, dt, J = 7.3, 1.5 Hz, Ar-H), 7.32 (2H, dt, J = 7.3, 1.5 Hz, Ar-H), 7.53 (2H, s, Ar-H), 7.73 (4H, dt, J = 7.3, 1.5 Hz, Ar-H); ¹³C NMR (100 MHz, CDCl₃) δ : 121.8, 123.4, 124.5, 124.8, 127.6, 131.0, 139.9, 143.4. LR-MS m/z: 346 (M⁺).

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Table 1	. Cu-catalvze	ed reaction of o	ganobismuth	and antimonv	compounds	1-8 with chalc	ogen element	s Y . ^a
	Y		8	Cu cat (10	mol%)		-8	
F	Ph、Î			Ligand (10	mol%)	V		
	M—Pr	י + Y <i>(</i> 5	Se Te) —	Ligana (10			+	Ph/Y_V/Ph
F	Ph∕		, 00, 10)	DMSO, 10	00 °C			TH T
	×			under Air				10a: V - S
						$\mathbf{Ja} \cdot \mathbf{A} = \mathbf{S}$		$10a_{1} \wedge - 3$
1a	:: M = Bi, X =	= Null				$90. \land - 3e$		$100. \land - 3e$
2 :	M = Bi, X =	Cl	$\langle - \rangle$			30 . A – Te		
3 :	M = Bi, X =	F 🦉	\rightarrow		>	\frown		
4 :	M = Bi, X =	OAc \=	N N=/	N N:	=∕ Me ₂ N	NMe ₂		~
5 :	M = Sb, X =	: Null	L1	L2		L3		
6 :	M = Sb, X =	CI						
7:	M = Sb, X =	F Molu		L prolino		DDh		
8 :	M = Sb, X =			L-proline				
			L4	L5		L6		
Entry	Substrate	V (S. Se. Te)	Culcat	ligand	Solvent	Time	Yie	ld (%)
Linu y	Substitute	1 (5, 50, 10)	Cu cut.	ingunu	Borvent	(h)	9 ^b	10 ^b
1	1a	S	CuOAc	L1	DMSO	24	9a : 36	10a : 21
2	1 a	Se	CuOAc	L1	DMSO	5	9b : 81	10b : <1
3	1a	Te	CuOAc	L1	DMSO	6	9c : <1	10c : <1
4	2	Se	CuOAc	L1	DMSO	24	9b : 31	10b : 62
5	3	Se	CuOAc	L1	DMSO	24	9b : 3	10b : 5
6	4	Se	CuOAc	L1	DMSO	24	9b : 35	10b : 46
7	5	Se	CuOAc	L1	DMSO	24	9b : 3	10b: ND
8	6	Se	CuOAc	L1	DMSO	24	9b: ND	10b: ND
9	7	Se	CuOAc	L1	DMSO	24	9b: ND	10b: ND
10	8	Se	CuOAc	L1	DMSO	24	9b : 8	10b : 5
11	1a	Se	CuI	L1	DMSO	24	9b : 82	10b : <1
12	1a	Se	CuBr	L1	DMSO	24	9b : 77	10b : <1
13	1a	Se	CuCl	L1	DMSO	24	9b : 75	10b : <1
14	1a	Se	CuO	L1	DMSO	24	9b : 67	10b : 4
15	1a	Se	$Cu(OAc)_2$	L1	DMSO	3	9b : 87 (85) ^c	10b : <1
16	1a	Se	CuBr ₂	L1	DMSO	24	9b : 79	10b: ND
17	1a	Se	CuCl ₂	L1	DMSO	24	9b : 75	10b : <1
18	1a	Se	CuO ₂	L1	DMSO	24	9b : 8	10b : 45
19	1a	Se			DMSO	24	9b: ND	10b : 18
20	1a	Se	$Cu(OAc)_2$	L2	DMSO	24	9b : 84	10b : <1
21	1a	Se	$Cu(OAc)_2$	L3	DMSO	24	9b : 76	10b : 2
22	1a	Se	$Cu(OAc)_2$	L4	DMSO	24	9b : 77	10b : 3
23	1a	Se	$Cu(OAc)_2$	L5	DMSO	24	9b : 70	10b : 5
24	1a	Se	$Cu(OAc)_2$	L6	DMSO	24	9b : 75	10b : 7
25	1a	Se	$Cu(OAc)_2$		DMSO	24	9b : 62	10b : 5
26	1a	Se	$Cu(OAc)_2$	L1	DMF	24	9b : 82	10b : <1
27	1a	Se	$Cu(OAc)_2$	L1	CH ₃ CN	24	9b : 60	10b : 16
28	1a	Se	$Cu(OAc)_2$	L1	NMP	24	9b : 27	10b : 5
29	1a	Se	$Cu(OAc)_2$	L1	Toluene	24	9b : 9	10b : 40
30	1a	Se	$Cu(OAc)_2$	L1	1,4-dioxan	e 24	9b : 8	10b : 35
31	1a	Se	$Cu(OAc)_2$	L1	1,2-DCE	24	9b : 8	10b : 26
32 ^d	1a	Se	$Cu(OAc)_2$	L1	DMSO	24	9b : 49	10b : 8
33 ^e	1a	Se	$Cu(OAc)_2$	L1	DMSO	2	9b : 80	10b : <1
$34^{\rm f}$	1a	Se	$Cu(OAc)_2$	L1	DMSO	24	9b : 62	10b : 3
35 ^g	1a	Se	$Cu(OAc)_2$	L1	DMSO	4	9b : 17	10b : 51

^a Condition: **1a-8** (0.5 mmol), chalcogen element (0.75 mmol), Cu cat (0.05 mmol), ligand (0.05 mmol). ^b GC yield using dibenzyl as internal standard. The yield 100% corresponds to the formation of 0.75 mmol of **9** and 0.375 mmol of **10**. ^c Isolated yield. ^d Under Ar.

^e Under O₂ ^f Cu cat (5 mol%). ^g Selenium (1.5 mmol)

Ar Bi	-Ar + So	Cu(OAc) ₂ 1,10-phen	(10 mol%) anthroline (10 mol%))) 2/2 x (Se		
Ar Ar + Se		DMS unde	60, 100 °C er Air	- 3/2 A (Ar Ar) 9b, 11-21		
Entry	Ar ₃ Bi	Ar	Time (h) ^b	Product	Yield (%) ^c	
1	1b		3	MeO-{_}-Se-{_}-OMe	11 : 87	
2	1c		3	Me	12 : 85	
3	1a	\rightarrow	3	Se-	9b : 85	
4	1d	– Č–ci	3	CI	13 : 87	
5	1e	-CO ₂ Et	3	EtO ₂ C-	14 : 84	
6	1f		2	F ₃ C-	15 : 90	
7	1g	Me	24	Me Se- Me	16 : 87	
8	1h	Me ————————————————————————————————————	24	MeMe Me—Se-Se-Se-Me MeMe	17 : 76	
9	1i	Me ₂ N	5	NMe2 Se Me2N	18 : 73	
10	1j		3	Se-	19 : 72	
11	1k	-s	1	 ſ_∕Se-∕_]	20 : 73	
12	11	-s	1	S Se S	21 : 77	

Table 2. Cu-catalyzed procedure for the synthesis of symmetrical diaryl selenides from triarylbismuthane 1 and selenium powder^a

^a **1** (0.5 mmol), Se (0.75 mmol), Cu(OAc)₂ (0.05 mmol), 1,10-phenanthroline (0.05 mmol). ^b Heating of the reaction mixture was terminated with extinction of **1** on TLC.

^c Isolated yield. The yield 100% corresponds to the involvement of three aryl groups on 1.



Fig. 1. Biologically active symmetrical diaryl selenides



Fig. 2. Reaction of triphenylbismuthane 1a with selenium

Retentiontime



