Palladium-Catalyzed Arylation of Azole Compounds with Aryl Halides in the Presence of Alkali Metal Carbonates and the Use of Copper Iodide in the Reaction

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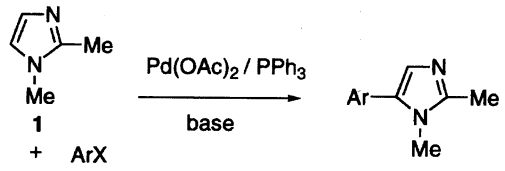
The reactions of iodobenzene with azole compounds, 1,2-disubstituted imidazoles and 2-substituted oxazoles and thiazoles, were examined in the presence of catalytic amounts of $Pd(OAc)_2$ and PPh_3 in DMF using alkali metal carbonates as bases. It was found that the coupling products, 5-arylazoles, could be selectively produced in good yields by using Cs_2CO_3. In the case that their 2-position is unsubstituted, the site could also be arylated. In reactions using bromobenzene in place of iodobenzene, K_2CO_3 was also as effective as Cs_2CO_3. The addition of a stoichiometric amount of CuI appeared to specifically promote the reactions of thiazoles as well as those of thiophene derivatives. The reactions of 2-unsubstituted azole compounds with aryl iodides could be mediated by CuI to some extent without using the palladium species to give 2-arylazoles.

Palladium-catalyzed substitution reactions of aryl halides and their synthetic equivalents, such as aryl triflates, are now recognized to be highly useful for the preparation of substituted aromatic compounds.[1] They involve arylpalladium(II) complexes as common intermediates, which react with various reagents, including alkenes, alkynes, and a number of organometallic species, to give the corresponding products. In the preparation of biaryls, arylboronic acids and arylstannanes are often employed as the coupling reagents (the Suzuki and Stille reactions, respectively). While aryl halides may also react directly with aromatic compounds accompanied by the cleavage of an aromatic C–H bond to produce biaryls, only intramolecular cases have been known to be generally effective.[1] Meanwhile, we have recently reported that 2-hydroxybenzaldehydes and [1,1′-biphenyl]-2-ols can react with aryl iodides in the presence of a palladium catalyst and an appropriate base via cleavage of the aldehyde and aromatic C–H bonds to give 2-aroylphenols and 2′-aryl-[1,1′-biphenyl]-2-ols, respectively, in which each phenolic function seems to act as a good anchor for the intermolecular reaction.[2] It was found that the former reaction was significantly promoted by the addition of a chloride source, such as LiCl; the latter one was markedly affected by the identity of the base employed. Ohta et al. also described that the intermolecular coupling of a number of five-membered aromatic heterocyclic compounds with specific substrates, 2-chloro-3,5-dialkylpyrazines, and the reaction of furans and thiophenes with aryl bromides are capable of proceeding catalytically by using $Pd(PPh_3)_4$ and AcOK, which has a significant advantage, not requiring stoichiometric metalation of the heterocycles.[3] Though the synthesis of aryl-substituted heterocyclic compounds is of pharmaceutically considerable interest,[3,4] the factors affecting the reaction were little explored. Consequently, we have investigated the effects of a base and an additive on the palladium-catalyzed reaction of azole compounds, including imidazoles, thiazoles, and oxazoles with aryl iodides and bromides. The results are described herein.

Results

The coupling reaction of 1,2-dimethyl-1*H*-imidazole (**1**) (1 mmol) with iodobenzene (**2a**) (2 mmol) was first examined in the presence of $Pd(OAc)_2$ (0.05 mmol) and PPh_3 (0.2 mmol) using a number of bases in DMF at 140 °C for 24 h (Scheme 1 and Entries 1—4 in Table 1). It was found that 1,2-dimethyl-5-phenyl-1*H*-imidazole (**3a**) was selectively produced as



2a: Ar = Ph, X = I
2a': Ar = Ph, X = Br
2b: Ar = 4-$MeOC_6H_4$, X = I
2b': Ar = 4-$MeOC_6H_4$, X = Br
2c: Ar = 4-ClC_6H_4, X = I
2c': Ar = 4-ClC_6H_4, X = Br
2d: Ar = 1-naphthyl, X= I
2d': Ar = 1-naphthyl, X= Br
2e: Ar = 2-naphthyl, X= I
2f: Ar = 6-MeO-2-naphthyl, X= I
2f': Ar = 6-MeO-2-naphthyl, X=Br
2g: Ar = 2-thienyl, X=Br

3a: Ar = Ph
3b: Ar = 4-$MeOC_6H_4$
3c: Ar = 4-ClC_6H_4
3d: Ar = 1-naphthyl
3e: Ar = 2-naphthyl
3f: Ar = 6-MeO-2-naphthyl
3g: Ar = 2-thienyl

Scheme 1.

Table 1. Reaction of 1,2-Dimethyl-1*H*-imidazole (**1**) with Iodobenzene (**2a**) or Bromobenzene (**2a′**)[a]

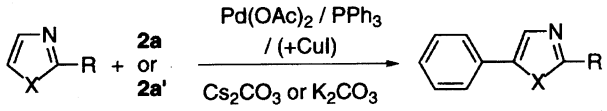
Entry	Halide	Base	Yield of **3a**[b]/%
1	**2a**	Na_2CO_3	23
2	**2a**	K_2CO_3	59
3	**2a**	Cs_2CO_3	83
4	**2a**	$N(n\text{-}Bu)_3$	0
5[c]	**2a**	Cs_2CO_3	72
6	**2a′**	Na_2CO_3	41
7	**2a′**	K_2CO_3	90
8	**2a′**	Cs_2CO_3	83
9[c]	**2a′**	K_2CO_3	84
10[d]	**2a**	Cs_2CO_3	67
11[e]	**2a**	Cs_2CO_3	73
12[d]	**2a′**	K_2CO_3	8

a) The reaction of **1** (1 mmol) with **2** (2 mmol) was carried out in the presence of $Pd(OAc)_2$ (0.05 mmol) and PPh_3 (0.1 mmol) in DMF (5 cm^3) under nitrogen at 140 °C for 24 h. b) Determined by GLC analysis based on amount of **1** used. In each reaction, formation of a small amount of diphenylated product (less than 4%) was detected by GC-MS analysis. c) In the absence of PPh_3. d) KI (1.0 mmol) was added. e) CsI (1.0 mmol) was added.

Table 2. Reaction of 1,2-Dimethyl-1*H*-imidazole (**1**) with Various Aryl Iodides or Bromides (**2**)[a]

Halide	Base	Time / h	Yield of **3**[b] / %
2a	Cs_2CO_3	48	93(83)
2a′	K_2CO_3	48	93(82)
2b	Cs_2CO_3	48	93(80)
2b′	K_2CO_3	24	85
2c	Cs_2CO_3	48	91(84)
2c′	K_2CO_3	24	85
2d	Cs_2CO_3	24	90(68)
2d′	K_2CO_3	24	86
2e	Cs_2CO_3	24	74(60)
2f	Cs_2CO_3	24	80(60)
2f′	K_2CO_3	24	75
2g	K_2CO_3	24	45
2g	Cs_2CO_3	48	43(41)

a) The reaction of **1** (1 mmol) with **2** (2 mmol) was carried out in the presence of $Pd(OAc)_2$ (0.05 mmol) and PPh_3 (0.1 mmol) in DMF (5 cm^3) under nitrogen at 140 °C. b) Determined by GLC analysis based on amount of **1** used. Value in parentheses indicates that after isolation.



4: X = NCH_2Ph, R = Me
5: X = NCH_2Ph, R = Me
6: X = O, R = Ph
7: X = O, R = Ph
8: X= S, R = Me
9: X= S, R = Me

Scheme 2.

the single major product when an alkali metal carbonate was used as the base. The product yield was found to highly depend on the identity of the base employed, increasing in the order $Na_2CO_3 < K_2CO_3 < Cs_2CO_3$. Thus, using Cs_2CO_3, product **3a** was obtained in a yield of 83% (93% after 48 h) based on the amount of **1** used. A tertiary amine, $N(n\text{-}Bu)_3$, was completely ineffective. The observed effect of the base, i.e. the relatively more soluble inorganic base, Cs_2CO_3, can significantly enhance the reaction, appears to be in harmony with that in the reaction of [1,1′-biphenyl]-2-ols with aryl iodides.[2b] It was of considerable interest that the reaction of **1** with bromobenzene (**2a′**) proceeded slightly faster by using K_2CO_3 compared with Cs_2CO_3 (Entries 6—8), indicating another factor other than the solubility of base intervenes. Note that the product yield was somewhat decreased in the absence of PPh_3 in both the reactions with **2a** and **2a′** (Entries 5 and 9).

The results for the reactions of **1** with aryl iodides **2a—f** using Cs_2CO_3 and with aryl bromides **2a′-d′**, **2f′**, and 2-bromothiophene (**2g**) using K_2CO_3 (Scheme 1) are summarized in Table 2. As expected, the corresponding 5-aryl-1,2-dimethyl-1*H*-imidazoles (**3**) were selectively obtained in fair-to-good yields.

1-Benzyl-2-methyl-1*H*-imidazole (**4**), 2-phenyloxazole (**6**), and 2-methylthiazole (**8**) reacted with **2a** or **2a′** in the presence of Cs_2CO_3 or K_2CO_3 to give the corresponding 5-phenyl derivatives **5**, **7**, and **9** in substantial yields (Scheme 2 and Entries 1—7 in Table 3). It was again observed that the reactions with **2a** using K_2CO_3 were relatively less efficient (Entries 2 and 5), whereas those with **2a′** using the base proceeded smoothly (Entries 3 and 6). We previously observed that a copper(I) species, such as CuI, can considerably promote the palladium-catalyzed carbonylation of aryl iodides.[5] Therefore, the effect of the addition of CuI on the reactions in Scheme 2 was examined. As a result, the reaction of **8** was found to be promoted by adding a stoichiometric amount of CuI, considerably increasing the yield of **9** (Entry 8), while no positive results were obtained in the reactions of **4** and **6**.

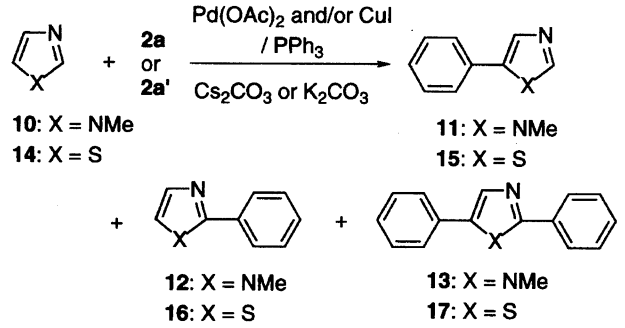
The reaction of 1-methyl-1*H*-imidazole (**10**) with **2a** or **2a′** gave 5-phenyl-1-methyl-1*H*-imidazole (**11**) as the major product together with 2,5-diphenyl-1-methyl-1*H*-imidazole (**13**) (Scheme 3 and Entries 9 and 10 in Table 3). From thiazole (**14**) and **2a** or **2a′** was similarly obtained a mixture of 5-phenylthiazole (**15**) and 2,5-diphenylthiazole (**17**) (Entries 13 and 14). It was interesting that in the presence of CuI the reaction of **10** with **2a** gave 2-phenyl-1-methyl-1*H*-imidazole (**12**) in 37% yield as a monophenylated product along with the diphenyl derivative **13** (40%), compound **11** being not detected (Entry 11). In the case of **14**, compound **17** was selectively obtained in 66% yield (Entry 15). It was confirmed that by using CuI alone, **12** (37%) and 2-phenylthiazole (**16**) (15%) were formed from **10** and **14**, respectively (Entries 12 and 16), no 5-phenylated products being detected.

The above-mentioned results indicate that (a) the 5-position of each azole compound is predominantly arylated in the presence of the palladium catalyst alone, which is consistent with the previously reported results using 2-chloro-3, 5-dialkylpyrazines,[3c] (b) the reaction of thiazoles are specifically enhanced by the addition of CuI, and (c) CuI itself may mediate the arylation at the 2-position of azoles to some

Table 3. Reaction of Various Azole Compounds with Iodo- (**2a**) and Bromobenzenes (**2a′**)[a]

Entry	Azole	Halide	$Pd(OAc)_2$ mmol	CuI mmol	Base	Time h	Product(s)[b] %
1	**4**	**2a**	0.05	—	Cs_2CO_3	48	**5**, 66(61)
2	**4**	**2a**	0.05	—	K_2CO_3	48	**5**, 45
3	**4**	**2a′**	0.05	—	K_2CO_3	24	**5**, 95(85)
4	**6**	**2a**	0.05	—	Cs_2CO_3	17	**7**, 88(79)
5	**6**	**2a**	0.05	—	K_2CO_3	17	**7**, 66
6	**6**	**2a′**	0.05	—	K_2CO_3	17	**7**, 90
7	**8**	**2a**	0.1	—	Cs_2CO_3	36	**9**, 43
8	**8**	**2a**	0.1	2	Cs_2CO_3	11	**9**, 68(55)
9	**10**	**2a**	0.1	—	Cs_2CO_3	20	**11**, (54), **13**(24)
10	**10**	**2a′**	0.1	—	K_2CO_3	20	**11**, 53; **13**, 33
11	**10**	**2a**	0.1	2	Cs_2CO_3	20	**12**, 37; **13**, 40
12[c]	**10**	**2a**	—	2	Cs_2CO_3	20	**12**, 37
13[d]	**14**	**2a**	0.1	—	Cs_2CO_3	47	**15**, 17; **17**, 35
14[d]	**14**	**2a′**	0.1	—	K_2CO_3	47	**15**, 24; **17**, 23
15[d]	**14**	**2a**	0.1	2	Cs_2CO_3	47	**17**, 66(66)
16[d]	**14**	**2a**	—	2	Cs_2CO_3	47	**16**, 15

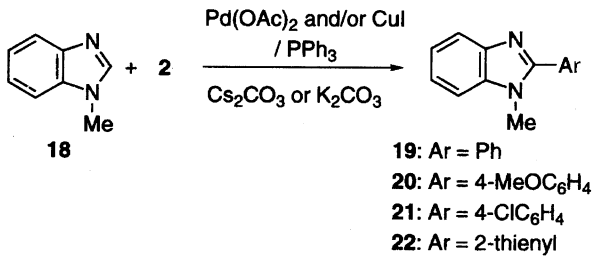
a) The reaction of azole (1 mmol) with **2** (2 mmol) was carried out in the presence of PPh_3 (P/Pd = 2) in DMF (5 cm^3) under nitrogen at 140 °C. b) Determined by GLC analysis based on amount of azole used. Value in parentheses indicates that after isolation. c) PPh_3 (0.6 mmol) was used. d) Reaction at 120 °C.



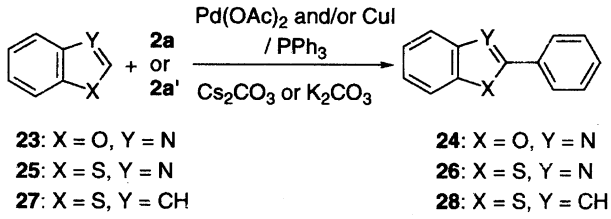
Scheme 3.

extents.

Consequently, 1-methyl-1*H*-benzimidazole (**18**), benzoxazole (**23**), and benzothiazole (**25**) were subjected to a reaction with **2a** or **2a′** in the presence of $Pd(OAc)_2$ (0.05 mmol) and/or CuI (2 mmol) together with Cs_2CO_3 or K_2CO_3 (Schemes 4 and 5 and Table 4). While the reaction of **18** with **2a** using $Pd(OAc)_2$ gave only a very small amount of the expected product **19** (2%) (Entry 1 in Table 4), a satisfactory yield (89%) could be attained by using CuI alone (Entry 3). Similarly, the reactions of **18** with **2b**, **2c**, and **2g** in the presence of CuI gave the corresponding 2-aryl-1-methyl-1*H*-



Scheme 4.



Scheme 5.

benzimidazoles **20**, **21**, and **22** in good yields (Entries 6—8). In contrast to the reaction of **18**, 2-phenylbenzoxazole (**24**) was smoothly produced from **23** by the palladium catalysis (Entries 9 and 10). The phenylation of **25** could also be catalyzed by the palladium species (Entries 12 and 13); as for the reactions of the azoles **8** and **14**, it was enhanced by the addition of CuI. In this case, a catalytic amount of the copper species was enough for a high yield coupling (Entry 15), but was less effective with CuI alone (Entry 16).

The phenylation reactions of benzo[*b*]thiophene (**27**) and 2-thiophenecarbaldehyde (**29**) were additionally carried out under the same conditions used for that of **25** (Schemes 5 and 6). The reaction of **27** effectively proceeded by using **2a′** in the presence of both $Pd(OAc)_2$ and CuI to give 2-phenylbenzo[*b*]thiophene (**28**) in more than 80% yield (Entries 19 and 20). Similarly, 5-phenyl-2-thiophenecarbaldehyde (**30**) was obtained in a yield of 82% by treating of **29** with **2a** (Entry 23), with the formation of 2-benzoylthiophene not being observed.[2a]

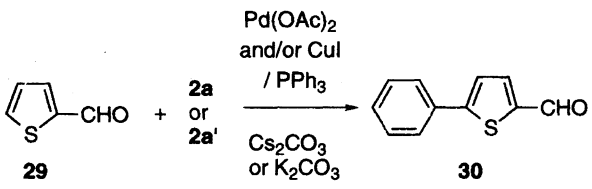
Discussion

The palladium-catalyzed arylation of azoles without using CuI is first discussed. The fact that in the arylation of 2-substituted and 4-unsubstituted azole compounds **1**, **4**, **6**, and **8**, their 5-position is predominantly attacked may imply that

Table 4. Reaction of Benzazoles and Thiophenes with Halobenzenes (**2**)[a]

Entry	Azole or Thiophene	Halide	$Pd(OAc)_2$ mmol	CuI mmol	Base	Time h	Product(s)[b] %
1	**18**	**2a**	0.05	—	Cs_2CO_3	36	**19**, 2
2	**18**	**2a**	0.05	2	Cs_2CO_3	8	**19**, 91(87)
3	**18**	**2a**	—	2	Cs_2CO_3	8	**19**, 89
4	**18**	**2a**	—	1	Cs_2CO_3	8	**19**, 33
5	**18**	**2a′**	—	2	Cs_2CO_3	8	**19**, 26
6[c]	**18**	**2b**	—	2	Cs_2CO_3	36	**20**, 76(73)
7[c]	**18**	**2c**	—	2	Cs_2CO_3	8	**21**, 84(78)
8	**18**	**2g**	—	2	Cs_2CO_3	24	**22**, 57(56)
9	**23**	**2a**	0.05	—	Cs_2CO_3	9	**24**, 95(88)
10	**23**	**2a′**	0.05	—	K_2CO_3	9	**24**, 58
11	**23**	**2a**	—	2	Cs_2CO_3	9	**26**, 15
12	**25**	**2a**	0.05	—	Cs_2CO_3	6	**26**, 40
13	**25**	**2a′**	0.05	—	K_2CO_3	6	**26**, 25
14	**25**	**2a**	0.05	2	Cs_2CO_3	6	**26**, 82(75)
15	**25**	**2a**	0.05	0.2	Cs_2CO_3	6	**26**, 91(86)
16	**25**	**2a**	—	2	Cs_2CO_3	6	**26**, 15
17	**27**	**2a**	0.05	—	Cs_2CO_3	19	**28**, 16
18	**27**	**2a**	0.05	2	Cs_2CO_3	21	**28**, 41
19	**27**	**2a′**	0.05	2	Cs_2CO_3	91	**28**, 89
20	**27**	**2a′**	0.05	2	K_2CO_3	99	**28**, 81
21	**27**	**2a**	—	2	Cs_2CO_3	48	**28**, 23
22	**29**	**2a**	0.05	—	Cs_2CO_3	21	**30**, 12
23	**29**	**2a**	0.05	2	Cs_2CO_3	21	**30**, 82
24	**29**	**2a′**	0.05	2	K_2CO_3	23	**30**, 57
25	**29**	**2a**	—	2	Cs_2CO_3	21	**30**, 0

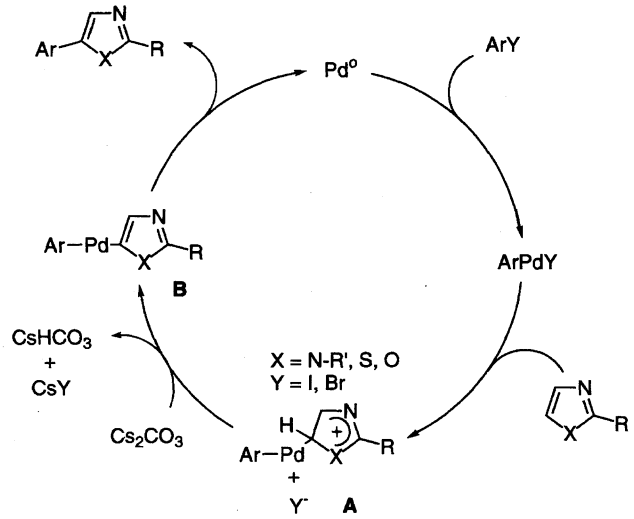
a) The reaction of benzazole or thiophene (1 mmol) with **2** (2 mmol) was carried out in the presence of $Pd(OAc)_2$ and/or CuI using PPh_3 (0.1 mmol) in DMF (5 cm^3) under nitrogen at 140 °C. b) Determined by GLC analysis based on amount of benzazole or thiophene used. Value in parentheses indicates that after isolation. c) PPh_3 (0.2 mmol) was used.



Scheme 6.

the reaction involves an electrophilic character: the reactivity order of the reaction sites in their electrophilic substitution is known to be C-5 > C-4 > C-2, although the compounds are generally relatively less reactive toward electrophiles.[6] Thus, it may be reasonable to consider that the catalytic reaction involves an electrophilic attack of the arylhalopalladium(II) species,[7] which is formed by the oxidative addition of aryl halide to the palladium(0) species generated in situ, onto an azole compound to form the σ-adduct of arylpalladium-(II) to the heterocyclic compound **A**; subsequent deprotonation gives the aryl(heteroaryl)palladium(II) intermediate **B** (Scheme 7, in which neutral ligands are omitted). Reductive elimination from **B** may give the corresponding arylation product.[8] While the participation of another route involving initial arylpalladation can not be completely ruled out, it seems unlikely to occur, since the *syn*-elimination of HPdY after the palladation is impossible.

The observed effect of the carbonate bases in the reaction



Scheme 7.

of **1** with **2a** (Table 1), i.e. $Cs_2CO_3 > K_2CO_3 > Na_2CO_3$, suggests that a carbonate base, which is relatively more soluble in DMF, may more effectively enhance the deprotonation step.[9] However, K_2CO_3 was as effective as Cs_2CO_3 in the reaction with **2a′**. It should be noted that KI (1.55) is significantly more soluble in DMF compared with KBr (0.065), CsBr (0.024), and CsI (0.23) (the value in paren-

theses indicates solubility in the solvent in mol dm^{-3} at 298 K calculated from literature data).[10] This led us to deduce that the reaction with **2a** using K_2CO_3 is prevented by the by-product KI. It was indeed confirmed that addition of KI (1 mmol) strongly suppressed the reaction of **1** with **2a′** in the presence of K_2CO_3 (Entry 12 in Table 1), whereas the effect of the addition was relatively small in the corresponding reaction of **2a** using Cs_2CO_3 (Entry 10). These results indicate that the solubilities of both alkali metal carbonates and alkali metal halides are important factors in determining the reaction efficiency.[11,12] The iodide ion may coordinate to ArPdX, thus preventing the reaction with azole to give **A**, whereas the sparingly soluble nature of KBr may promote the reaction with **2a′**, probably in the transformation of **A** to **B** step in the absence of iodide ion.

The results for the reactions of **10**, **14**, **23**, and **25** indicate that even their 2-position, which is the least-reactive site,[6] can also be attacked by arylpalladium(II) species, while the first arylation of **10** and **14** appears to take place preferably at the 5-position. Although the details concerning the reaction mode at the 2-position is not definitive at the present stage, the fact that the hydrogen attached at the position in each azole compound is relatively more acidic[6] seems to enable arylation. It is noted that under the present conditions the reactions of benzo[*b*]furan and 1-methylindole with **2a** in the presence of $Pd(OAc)_2$ using Cs_2CO_3 gave the corresponding 2-phenylated products in rather low yields of 5 and 8%, respectively, although the substrates are relatively more susceptible toward electrophiles. Therefore, the acidity of the hydrogen, which is replaced in the reaction, may also be one of the significant factors in determining the reaction efficiency.

The palladium-catalyzed arylation of thiazoles **8**, **14**, and **25** as well as thiophenes **27** and **29** was observed to be considerably promoted by the addition of CuI. The results of control experiments indicate that the arylation apparently requires both the palladium and copper species to obtain reasonable product yields. Though the role of the copper species is not definitive, the coordination of the sulfur-containing heterocyclic compounds to the soft metal would increase their reactivity.

The reactions of 2-unsubstituted azoles **10**, **18**, **23**, and **25** with **2a** in the presence of CuI alone gives the corresponding 2-phenylated products in various yields. The arylation would be regarded as being nucleophilic substitution reaction of aromatic iodide assisted by a base and a Cu(I) species.[13] This is partly supported by the fact that the hydrogen at the 2-position is considerably susceptible toward the base.[6] The reasons that the reaction of 1-methyl-1*H*-benzimidazole (**18**) with **2** was exceptionally efficient, and using $Pd(OAc)_2$ alone was almost ineffective, are unclear.

Experimental

The ^1H and ^{13}C NMR spectra were recorded on a JEOL JNM-GSX spectrometer at 400 and 100 MHz, respectively, for $CDCl_3$ solutions. GLC-MS data were obtained with a Shimadzu QP-2000A spectrometer. GLC analysis was carried out using a Shimadzu GC 8A gas chromatograph equipped with a Silicone OV-17 glass column (ϕ2.6 mm×1.5 m) or with a CBP-1 capillary column (ϕ0.5 mm×25 m). 2-Iodonaphthalene (**2e**),[14] 2-phenyloxazole (**6**)[15] and 2-methylthiazole (**8**)[16] were prepared according to published procedures. Other starting materials were commercially available. DMF was distilled over CaH_2 before use. The following experimental details may be regarded as being typical in methodology and scale.

Reaction of 1,2-Dimethyl-1*H*-imidazole (1) with Iodobenzene (2a). In a 100 cm^3 two-necked flask was placed Cs_2CO_3 (652 mg, 2 mmol), which was then dried at 150 °C in vacuo for 2 h. Then, **1** (96 mg, 1 mmol), **2a** (408 mg, 2 mmol), $Pd(OAc)_2$ (11.2 mg, 0.05 mmol), PPh_3 (26.2 mg, 0.1 mmol), and DMF (5 cm^3) were added, and the resulting mixture was stirred under nitrogen at 140 °C for 48 h. After cooling, the mixture was poured into aqueous sodium hydroxide, extracted with dichloromethane, and dried over sodium sulfate. Product **3a** (143 mg, 83%) was isolated by column chromatography on silica gel using hexane–ethyl acetate (1 : 2, v/v) as an eluent.

1,2-Dimethyl-5-phenyl-1*H*-imidazole (3a): Mp 74 °C (lit,[17] 76 °C); MS *m/z* 172 (M^+); ^1H NMR δ = 2.45 (3H, s), 3.53 (3H, s), 6.95 (1H, s), 7.33—7.46 (5H, m).

1,2-Dimethyl-5-(4-methoxyphenyl)-1*H*-imidazole (3b): Mp 112—113 °C; MS *m/z* 202 (M^+); ^1H NMR δ = 2.43 (3H, s), 3.48 (3H, s), 3.84 (3H, s), 6.88 (1H, s), 6.96 (2H, dt, J = 8.8, 2.9 Hz), 7.27 (2H, dt, J = 8.8, 2.9 Hz). Found: C, 71.27; H, 6.94; N, 13.73%. Calcd for $C_{12}H_{14}N_2O$: C, 71.26; H, 6.98; N, 13.85%.

1,2-Dimethyl-5-(4-chlorophenyl)-1*H*-imidazole (3c): Mp 110.5—111.5 °C; MS *m/z* 206, 208 (M^+); ^1H NMR δ = 2.45 (3H, s), 3.51 (3H, s), 6.94 (1H, s), 7.28 (2H, dt, J = 8.3, 2.0 Hz), 7.40 (2H, dt, J = 8.3, 2.4 Hz). Found: C, 64.19; H, 5.41; N, 13.31; Cl, 16.88%. Calcd for $C_{11}H_{11}N_2Cl$: C, 63.93; H, 5.37; N, 13.55; Cl, 17.15%.

1,2-Dimethyl-5-(1-naphthyl)-1*H*-imidazole (3d): Oil; MS *m/z* 222 (M^+); ^1H NMR δ = 2.50 (3H, s), 3.27 (3H, s), 7.02 (1H, s), 7.42—7.54 (4H, m), 7.69 (1H, d, J = 8.3 Hz), 7.91 (2H, d, J = 8.3 Hz). HRMS Found: *m/z* 222.1155. Calcd for $C_{15}H_{14}N_2$: M, 222.1157.

1,2-Dimethyl-5-(2-naphthyl)-1*H*-imidazole (3e): Mp 170 °C; MS *m/z* 222 (M^+); ^1H NMR δ = 2.48 (3H, s), 3.59 (3H, s), 7.06 (1H, s), 7.46—7.52 (3H, m), 7.81—7.90 (4H, m). Found: C, 81.01; H, 6.37; N, 12.22%. Calcd for $C_{15}H_{14}N_2$: C, 81.05; H, 6.35; N, 12.60%.

1,2-Dimethyl-5-(6-methoxy-2-naphthyl)-1*H*-imidazole (3f): Mp 164 °C; MS *m/z* 252 (M^+); ^1H NMR δ = 2.47 (3H, s), 3.57 (3H, s), 3.94 (3H, s), 7.02 (1H, s), 7.15—7.20 (2H, m), 7.43 (1H, d, J = 8.3 Hz), 7.73—7.79 (3H, m). Found: C, 76.56; H, 6.16; N, 10.49%. Calcd for $C_{16}H_{16}N_2O$: C, 76.17; H, 6.39; N, 11.10%.

1,2-Dimethyl-5-(2-thienyl)-1*H*-imidazole (3g): Bp 120 °C/2 mmHg (1 mmHg = 133.322 Pa); MS *m/z* 178 (M^+); ^1H NMR δ = 2.44 (3H, s), 3.57 (3H, s), 7.03—7.04 (2H, m), 7.09 (1H, dd, J = 3.4, 4.9 Hz), 7.34 (1H, d, J = 4.9 Hz). HRMS: Found: *m/z* 178.0561. Calcd for $C_9H_{10}N_2S$: M, 178.0581.

1-Benzyl-2-methyl-5-phenyl-1*H*-imidazole (5): Mp 88.5—89.5 °C; MS *m/z* 248 (M^+); ^1H NMR δ = 2.32 (3H, s), 5.12 (2H, s), 6.95 (2H, d, J = 7.3 Hz), 7.06 (1H, s), 7.25—7.36 (8H, m). Found: C, 82.19; H, 6.61; N, 11.19%. Calcd for $C_{17}H_{16}N_2$: C, 82.23; H, 6.49; N, 11.28%.

2,5-Diphenyloxazole (7): Mp 71—71.5 °C (lit,[18] 71—73 °C); MS *m/z* 221 (M^+); ^1H NMR δ = 7.34 (1H, tt, J = 1.5, 7.8 Hz), 7.43—7.51 (6H, m), 7.73 (2H, d, J = 9.8 Hz), 8.12 (2H, d, J = 9.8 Hz).

2-Methyl-5-phenylthiazole (9): Mp 80—80.5 °C (lit,[19] 84 °C); MS *m/z* 175 (M^+); ^1H NMR δ = 2.73 (3H, s), 7.30 (1H, tt,

J = 1.5, 7.3 Hz), 7.38 (2H, tt, J = 1.5, 7.3 Hz), 7.52 (2H, d, J = 8.3 Hz), 7.79 (1H, s).

1-Methyl-5-phenyl-1*H*-imidazole (11): Mp 94.5—95.5 °C (lit,[20] 96—97 °C); MS *m/z* 158 (M^+); ^{1}H NMR δ = 3.67 (3H, s), 7.10 (1H, s), 7.37—7.44 (5H, m), 7.52 (1H, s).

1-Methyl-2-phenyl-1*H*-imidazole (12): Oil;[21] MS *m/z* 158 (M^+); ^{1}H NMR δ = 3.74 (3H, s), 6.97 (1H, d, J = 1.0 Hz), 7.13 (1H, d, J = 1.5 Hz), 7.40—7.46 (3H, m), 7.61—7.64 (2H, m).

1-Methyl-2,5-diphenyl-1*H*-imidazole (13): Mp 183—184 °C (lit,[22] 172—174 °C); MS *m/z* 234 (M^+); ^{1}H NMR δ = 3.69 (3H, s), 7.21 (1H, s), 7.45—7.49 (8H, m), 7.69—7.72 (2H, m); ^{13}C NMR δ = 33.62, 127.41, 127.74, 128.42, 128.50, 128.54, 128.63, 128.65, 130.13, 130.80, 135.29, 149.24.

5-Phenylthiazole (15): Mp 45 °C (lit,[23] 44—45 °C); MS *m/z* 161 (M^+); ^{1}H NMR δ = 7.35—7.44 (3H, m), 7.58 (2H, dt, J = 8.3, 2.4 Hz), 8.08 (1H, s), 8.76 (1H, s).

2-Phenylthiazole (16): Oil;[24] MS *m/z* 161 (M^+); ^{1}H NMR δ = 7.33 (1H, d, J = 3.4 Hz), 7.41—7.46 (3H, m), 7.87 (1H, d, J = 3.4 Hz), 7.96—7.98 (2H, m).

2,5-Diphenylthiazole (17): Mp 106—106.5 °C (lit,[25] 103—104 °C); MS *m/z* 237 (M^+); ^{1}H NMR δ = 7.34—7.48 (6H, m), 7.61 (2H, dt, J = 6.8, 1.5 Hz), 7.95—7.99 (2H, m), 8.02 (1H, s).

1-Methyl-2-phenyl-1*H*-benzimidazole (19): Mp 94—95 °C (lit,[26] 94—95 °C); MS *m/z* 208 (M^+); ^{1}H NMR δ = 3.87 (3H, s), 7.31—7.35 (2H, m), 7.40 (1H, dt, J = 9.3, 2.9 Hz), 7.50—7.55 (3H, m), 7.77 (2H, dt, J = 9.8, 2.0 Hz), 7.83 (1H, dt, J = 9.3, 2.9 Hz).

1-Methyl-2-(4-methoxyphenyl)-1*H*-benzimidazole (20): Mp 118.5—119.5 °C; MS *m/z* 238 (M^+); ^{1}H NMR δ = 3.85 (3H, s), 3.88 (3H, s), 7.04 (2H, dt, J = 8.8, 2.0 Hz), 7.29—7.32 (2H, m), 7.36—7.38 (1H, m), 7.72 (2H, dt, J = 8.8, 2.9 Hz), 7.79—7.82 (1H, m). Found: C, 75.49; H, 5.91; N, 11.78%. Calcd for $C_{15}H_{14}N_2O$: C, 75.61; H, 5.92; N, 11.76%. HRMS Found: *m/z* 238.1097. Calcd for $C_{15}H_{14}N_2O$: M, 238.1106.

1-Methyl-2-(4-chlorophenyl)-1*H*-benzimidazole (21): Mp 112.5—113.5 °C; MS *m/z* 242, 244 (M^+); ^{1}H NMR δ = 3.85 (3H, s), 7.30—7.36 (2H, m), 7.38—7.40 (1H, m), 7.51 (2H, dt, J = 8.3, 2.0 Hz), 7.72 (2H, dt, J = 8.8, 2.0 Hz), 7.81—7.83 (1H, m). Found: C, 69.04; H, 4.68; N, 11.49; Cl, 14.65%. Calcd for $C_{14}H_{11}N_2Cl$: C, 69.28; H, 4.57; N, 11.54; Cl, 14.61%. HRMS Found: *m/z* 242.0610. Calcd for $C_{14}H_{11}N_2Cl$: M, 242.0611.

1-Methyl-2-(2-thienyl)-1*H*-benzimidazole (22): Mp 84—85 °C; MS *m/z* 214 (M^+); ^{1}H NMR δ = 3.97 (3H, s), 7.19 (1H, dd, J = 3.9, 4.9 Hz), 7.28—7.36 (3H, m), 7.52 (1H, dd, J = 1.0, 4.9 Hz), 7.57 (1H, dd, J = 1.0, 3.9 Hz), 7.78—7.82 (1H, m). HRMS Found: *m/z* 214.0585. Calcd for $C_{12}H_{10}N_2S$: M, 214.0582.

2-Phenylbenzoxazole (24): Mp 102—103 °C (lit,[27] 101—103 °C); MS *m/z* 195 (M^+); ^{1}H NMR δ = 7.33—7.38 (2H, m), 7.50—7.54 (3H, m), 7.56—7.61 (1H, m), 7.76—7.80 (1H, m), 8.24—8.29 (2H, m).

2-Phenylbenzothiazole (26): Mp 115 °C (lit,[28] 115—116 °C); MS *m/z* 211 (M^+); ^{1}H NMR δ = 7.39 (1H, t, J = 7.8 Hz), 7.47—7.51 (4H, m), 7.91 (1H, d, J = 7.8 Hz), 8.07—8.12 (3H, m).

2-Phenylbenzo[*b*]thiophene (28): Mp 174—175.5 °C (lit,[29] 175.5—176 °C); MS *m/z* 210 (M^+); ^{1}H NMR δ = 7.30—7.36 (3H, m), 7.42 (2H, t, J = 7.3 Hz), 7.54 (1H, s), 7.71 (2H, d, J = 8.3 Hz), 7.77 (1H, d, J = 8.3 Hz), 7.83 (1H, d, J = 8.3 Hz).

5-Phenyl-2-thiophenecarbaldehyde (30): Mp 92 °C (lit,[30] 92—93 °C); MS *m/z* 188 (M^+); ^{1}H NMR δ = 7.41 (1H, d, J = 3.9 Hz), 7.37—7.46 (3H, m), 7.66—7.69 (2H, m), 7.75 (1H, d, J = 3.9 Hz), 9.89 (1H, s).

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