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REACTION OF DIAZONIUM SALTS WITH TRANSITION METALS

X *. FORMYLATION OF ARENEDIAZONIUM SALTS WITH CARBON MONOXIDE AND SILYL HYDRIDES UNDER PALLADIUM CATALYSIS

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Summary

Arenediazonium tetrafluoroborates (ArN_2BF_4 where Ar = X-C_6H_4; X = H, 2-Me, 3-Me, 4-Me, 4-MeO, 4-MeCO, 4-EtOCO, 2-Ph, 2-Cl, 3-Cl, 4-Cl, 4-Br, 4-I, 3-NO_2 and 4-NO_2) were easily converted to aromatic aldehydes (ArCHO) in good yields through the palladium-catalyzed reaction with CO and Et_3SiH or polymethylhydrosiloxane (PMHS) at room temperature.

Introduction

In view of the easy availability of arenediazonium salts (ArN_2X) with various substituents, formylation of ArN_2X is an attractive method for the synthesis of aromatic aldehydes. The copper-catalyzed reaction of ArN_2Cl with formaldoxime has been reported to give arylated oximes which are hydrolyzed to aldehydes (eq. 1) [2]. However, the yields depended on the substituents on ArN_2Cl and were generally low.

$$ArN_2Cl + CH_2{=}NOH \xrightarrow{CuSO_4} ArCH{=}NOH \dashrightarrow ArCHO \qquad (1)$$

Novel palladium-catalyzed reactions of ArN_2BF_4 with Me_4Sn and RCOONa under CO pressure, in which the arylpalladium species is assumed to be an intermediate, afforded excellent methods for the transformation of ArN_2BF_4 to ArCOMe [3] and ArCOOCOR [4], respectively. Herein we report the direct transformation of ArN_2BF_4 to ArCHO by CO and Et_3SiH or polymethylhydrosiloxane (PMHS) in the presence of a catalytic amount of $Pd(OAc)_2$.

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* For Part IX, see ref. 1.

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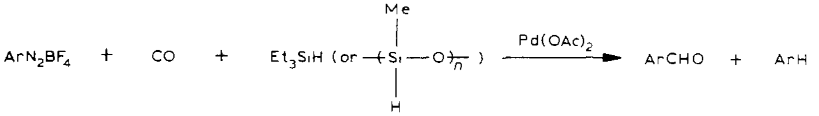
Results and discussion

The addition of ArN_2BF_4 and $Pd(OAc)_2$ to a solution of Et_3SiH or PMHS in 1/1 (v/v) CH_3CN/Et_2O under a CO pressure of 10 kg/cm^2 at room temperature afforded ArCHO together with small amounts of the reduction product ArH (eq. 2).



$$ArN_2BF_4 + CO + Et_3SiH \ (\text{or } \lbrace \overset{Me}{\underset{H}{Si}} - O \rbrace_n) \xrightarrow{Pd(OAc)_2} ArCHO + ArH \quad (2)$$

Table 1 shows the effects of the reaction conditions on the formylation of 4-Br-$C_6H_4N_2BF_4$. Use of the mixed solvent (CH_3CN/Et_2O in 1/1 ratio) was required to obtain good yields of ArCHO. A smaller amount of $Pd(OAc)_2$ (0.2 mol%) also gave satisfactory results. In the absence of $Pd(OAc)_2$, ArN_2BF_4 was reduced to ArH slowly and no ArCHO was observed. The reaction with Et_3SiH was completed within 2 min, whereas that with PMHS required 4 h. In order to obtain satisfactory results, 10 kg/cm^2 of CO should be used. Under atmospheric pressure of CO, the reaction with PMHS gave 48% of ArCHO, but that with Et_3SiH gave only ArH and no ArCHO.

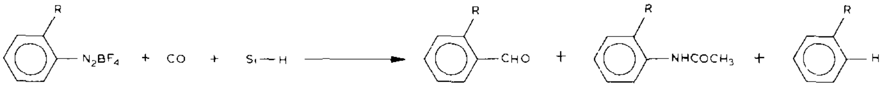
Typical results of the formylation of various ArN_2BF_4 compounds are summarized in Tables 2 (with Et_3SiH) and 3 (with PMHS). The initial pale yellow homogeneous solution rapidly turned to a colorless solution containing fine black particles at the end of reaction, i.e. complete consumption of ArN_2BF_4. Although most of the reactions with Et_3SiH (Table 2) were completed within 2 min, all the reactions were allowed to continue for 10 min. The reactions with PMHS, however, were very slow at room temperature and required 4 to 12 h for completion. All substituents except for 2-NO_2 on the aromatic ring examined here gave good yields of ArCHO. Nitrobenzene was obtained as the main product from 2-NO_2-$C_6H_4N_2BF_4$. Generally better results were obtained with PMHS than with Et_3SiH. In the case of *ortho*-substituted ArN_2BF_4, the use of PMHS, however, drastically reduced the yields of ArCHO and considerable amounts of acetanilides ($ArNHCOCH_3$) were obtained (eq. 3). Some *ortho*-substituted ArN_2BF_4 compounds

TABLE 1

EFFECTS OF REACTION CONDITIONS ON THE FORMYLATION OF 4-Br-$C_6H_4N_2BF_4$ [a]

No.	Si-H	Solvent [b]	$Pd(OAc)_2$ (mol%)	CO (kg/cm^2)	Reaction time (min)	Product ratio [c] (ArCHO/ArH)	Yields (%) [d] of ArCHO
1	Et_3SiH	A	2	10	10	(52/48)	25
2	Et_3SiH	A-E	2	10	10	(94/6)	71
3	Et_3SiH	A-E	0.2	10	10	(91/9)	68
4	Et_3SiH	A-E	2	3	10	(68/32)	52
5	Et_3SiH	A-E	2	1	20	(0/100)	0 [e]
6	PMHS	A	2	10	720	–	No reaction
7	PMHS	A-E	2	10	240	(99/1)	86
8	PMHS	A-E	2	1	300	(70/30)	48

[a] The reactions were performed with 10 mmol of 4-Br-$C_6H_4N_2BF_4$, 11 mmol of Et_3SiH (or 14 mmol of PMHS) and $Pd(OAc)_2$ in 100 ml of the solvent at room temperature. [b] A: CH_3CN (50 ml), A-E: CH_3CN (50 ml) Et_2O (50 ml). [c] Determined by GC analysis before isolation. [d] Isolated yields of 4-Br-C_6H_4CHO based on 4-Br-$C_6H_4N_2BF_4$ used. [e] Bromobenzene was isolated in 79% yield



(3)

R		CHO	NHCOCH₃	H
R = Me	PMHS (300 min)	21%	31%	—
	Et_3SiH (10 min)	79%	0%	—
R = Ph	PMHS (420 min)	21%	36%	29%
	Et_3SiH (10 min)	84%	0%	14%

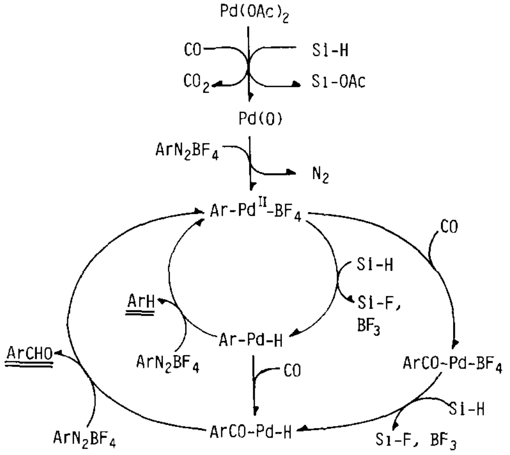
(The values are isolated yield based on ArN_2BF_4)

have been known to react readily with nitrile to give nitrilium ions [5,6], which are hydrolyzed to amides (eq. 4). Thus, the formation of anilides can be attributed to the

$$ArN_2BF_4 + CH_3CN \rightarrow [CH_3C{\equiv}N\text{-}Ar]^+\ BF_4^- \xrightarrow{H_2O} ArNHCOCH_3 \qquad (4)$$

low reactivity of PMHS and the high reactivity of *ortho*-substituted ArN_2BF_4 to CH_3CN.

The following scheme reasonably explains the present palladium-catalyzed formylation of ArN_2BF_4. Both CO and Si–H can easily reduce divalent palladium to



SCHEME 1

zero-valent palladium, which reacts with ArN_2BF_4 to give Ar-Pd species under very mild conditions. The formation of Ar-Pd species and the insertion of CO might be fast at room temperature. In the case of PMHS, the hydride exchange reaction should be the rate-determining step. On the other hand, in the case of Et_3SiH, the hydride exchange may compete with the CO insertion. Thus, under atmospheric pressure of CO, Et_3SiH gave only the reduction product ArH.

Direct formylation involving electrophilic attack on the aromatic ring, such as the Gatterman-Koch ($CO\text{-}HCl\text{-}AlCl_3$) [7], the Gatterman (HCN-HCl) [8] and the Vilsmeyer ($RR'NCHO\text{-}P(O)Cl_3$) [9] reactions, has been conveniently utilized for the synthesis of aromatic aldehydes. *meta*-Directing groups on the aromatic ring, however, usually prevent formylation in Friedel–Crafts acylations.

Formylation of aryl halides via organometallics, such as ArLi and ArMgBr, is

TABLE 2

FORMYLATION OF ArN_2BF_4 WITH Et_3SiH AND CO UNDER PALLADIUM CATALYSIS[a]

No.	Ar: X in $X\text{-}C_6H_4N_2BF_4$	Product ratio[b] (ArCHO/ArH)	Yields (%)[c] of ArCHO	B.p (m.p.) (°C/mmHg (°C))	lit m.p (°C)
9	2-Me	–[e]	79	60–90/10,[d] [196][f]	[193][f,g]
10	3-Me	–[e]	61	60–80/8,[d] [196][f]	[194][f,g]
11	4-Me	–[e]	77	60–70/6,[d] [235–236][f]	[234][f,g]
12	2-Ph	(85/15)	84	90.4–91 0/0.2	150/7[h]
13	2-Cl	(94/6)	78	70–95/15,[d] [208–209][f]	[207][f,g]
14	3-Cl	(91/9)	79	80–95/8,[d] [258–260][f]	[256][f,g]
15	4-Cl	(95/5)	71	(44–46)	(44–47)[i]
16	4-Br	(94/6)	71	(55–56)	(55–58)[i]
17	$4\text{-}COCH_3$	(95/5)	72	(28–29)	(33–34)[i]
18	4-COOEt	(93/7)	83	106.4–106.7/2	142/13[h]
19	$2\text{-}NO_2$	(3/97)	–[k]	–	–
20	$3\text{-}NO_2$	(78/22)	75	(56–58)	(57–59)[i]
21	$4\text{-}NO_2$	–[e]	85	(104–106)	(105–108)[i]

[a] The reactions were performed with 10 mmol of ArN_2BF_4, 11 mmol of Et_3SiH and 0.2 mmol of $Pd(OAc)_2$ in CH_3CN (50 ml) and Et_2O (50 ml) under 10 kg/cm^2 of CO at room temperature for 10 min. [b] Determined by GC analysis before isolation. [c] Isolated yields of ArCHO based on ArN_2BF_4. [d] Bath temperature of Kugelrohr distillation. [e] Not determined. [f] Melting points of the corresponding 2,4-dinitrophenylhydrazones. [g] R.L. Shriner, R.C. Fuson and D.Y. Curtin, Systematic Identification of Organic Compounds, 4th Ed., John Wiley & Sons, Inc., New York, 1956. [h] Cited from Beilstein's Handbuch der Organischen Chemie. [i] Cited from Merck Index, 9th Ed., 1976 [j] D. Milstein and J K Stille, J. Org. Chem., 44(1979) 1613. [k] Nitrobenzene was isolated in 81% yield.

another common method [10]. But most of the *meta*-directing groups in this case too cannot be included in the starting halides.

The palladium-catalyzed formylation of aryl halides with CO and H_2 (1/1) is closely related to the present reaction; this reaction, however, required a higher temperature (~100 °C) and pressure (1200–1400 psi) [11]. Recently, Baillargeon and Stille reported the more closely related formylation of organic halides with CO and $n\text{-}Bu_3SnH$ catalyzed by $Pd(O)(PPh_3)_4$ [12]. Because of the high reactivity of the diazonium group, halo-substituted, especially iodo-substituted, aromatic aldehydes

TABLE 3

FORMYLATION OF ArN_2BF_4 WITH PMHS AND CO UNDER PALLADIUM CATALYSIS[a]

No.	Ar: X in $X\text{-}C_6H_4N_2BF_4$	Reaction time (h)	Product ratio[b] (ArCHO/ArH)	Yields (%)[c] of ArCHO
22	4-Me	12	(99/1)	60
23	4-MeO	12	(91/9)	73
24	4-Cl	12	(99/1)	93
25	4-Br	4	(99/1)	86
26	4-I	4	–[d]	59
27	4-COOEt	7	(97/3)	84
28	$4\text{-}NO_2$	7	(95/5)	83

[a] The reactions were performed with 10 mmol of ArN_2BF_4, 14 mmol of PMHS and 0.2 mmol of $Pd(OAc)_2$ in CH_3CN (50 ml) and Et_2O (50 ml) under 10 kg/cm^2 of CO at room temperature. [b] Determined by GC analysis before isolation. [c] Isolated yields of ArCHO based on ArN_2BF_4. [d] Not determined.

can be prepared chemoselectively from halo-substituted arylamines. Furthermore, some aryl halides are commonly prepared regioselectively from ArN_2X. Consequently the present palladium-catalyzed formylation of ArN_2BF_4 provides a convenient method for regioselective synthesis from readily available starting materials.

Experimental

Materials. Acetonitrile was distilled from phosphorus pentoxide (twice) and calcium hydride under nitrogen. Diethyl ether was distilled from sodium metal. Liquid arylamines were distilled before use. Guaranteed reagents of crystalline arylamines were used as received. Arenediazonium tetrafluoroborates were prepared by the usual method [13] and stored under nitrogen at −20 °C. Palladium acetate was prepared by the method of ref. 14. Et_3SiH and PMHS were used as received.

General procedure. A solution of Et_3SiH (11 mmol) or PMHS (14 mmol) in CH_3CN (50 ml) and Et_2O (50 ml) was placed in a 300 ml glass autoclave, and ArN_2BF_4 (10 mmol) and $Pd(OAc)_2$ (0.2 mmol), which were wrapped in a piece of Saran film, were held loosely above the liquid surface by using a stirring rod. After the introduction of 10 kg/cm^2 of CO, ArN_2BF_4 and $Pd(OAc)_2$ were mixed by rotating the stirring rod that held them. Completion of the reaction was easily discerned by the change in the initial homogeneous pale yellow solution to a black dispersion (maybe palladium black). After CO had been purged, 100 ml of Et_2O was added to the mixture and then the mixture was filtered. The filtrate was washed with aqueous sodium bicarbonate and brine, and then dried over anhydrous magnesium sulfate. The product composition of this solution was determined by GC analysis. Aldehydes were easily separated from the reduction products (ArH) and isolated by silica gel chromatography or Kugelrohr distillation. Reasonable IR and NMR spectra were obtained for all the aldehydes prepared. Melting points and/or boiling points are listed in Table 2.

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