[Chem. Pharm. Bull. 30(3) 777—781 (1982)]

Hydroalkylation of Aniline with Pd-Al_2O_3 and NaCl-$AlCl_3$

Tsutomu Kamiyama,* Saburo Enomoto and Masami Inoue

Faculty of Pharmaceutical Sciences, Toyama Medical and Pharmaceutical University, 2630 Sugitani, Toyama, 930-01, Japan

(Received July 1, 1981)

The hydroalkylation of aniline in a palladium-fused salt system was examined under hydrogen pressure. By using 0.5% Pd–Al_2O_3 and fused salt (NaCl–$AlCl_3$), *N*-cyclohexylaniline (4) was formed as the main product at temperatures below 300°C; at higher temperatures, the cyclohexyl group rearranged to form nuclear alkylated products, *o*- and *p*-cyclohexylaniline, (5) and (6). The yield of **4** was 27.7% at 280°C; those of **5** and **6** were 5.4 and 7.3%, respectively, at 400°C. The reaction mechanism for the hydroalkylation of aniline with this catalytic system is discussed.

Keywords——hydroalkylation; combination catalyst system; palladium-fused salt; aniline; *N*-cyclohexylaniline; cyclohexylanilines; dicyclohexylamine

We previously reported that the combination catalyst of palladium and fused salt (NaCl–$AlCl_3$) showed good activity for the hydroalkylation of benzene to cyclohexylbenzene.1,2) This catalyst system was applied to the hydroalkylation of aniline. Catalytic hydrogenation of primary arylamines and cyanides often results in the formation of secondary amines, as well as the desired primary amines.3) In the hydrogenation of aniline, dicyclohexylamine (3) and *N*-cyclohexylaniline (4) have been obtained as by-products.4) In our catalytic system, **4** was prepared from aniline in good yield at 280°C; at higher temperatures, nuclear alkylated products were obtained.

We now report on the hydroalkylation of aniline using palladium and fused salt. The reaction mechanism of the hydroalkylation of aniline is also discussed.

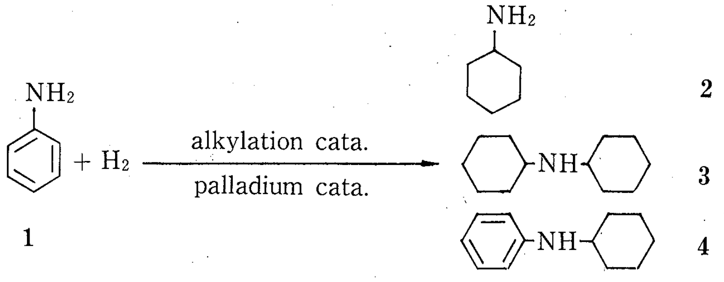
Results and Discussion

1) Hydroalkylation of Aniline with Various Catalysts

This reaction was carried out using a palladium-fused salt system prepared from alkaline metal chlorides and Friedel–Crafts type catalysts (Table I).

On Pd–Al_2O_3, cyclohexylamine (2) and **3** were obtained as the main products. The addition of aluminum chloride inhibited the hydrogenation of aniline completely, as has been observed in the hydroalkylation of benzene.2) However, when Friedel–Crafts catalysts were added in the form of fused salt, hydrogenation occurred and both hydrogenated and alkylated products were obtained. For example, in 5 h at 180°C, **2** (8.6%), **3** (12.7%), **4** (30.1%) were obtained in the presence of 1.0% Pd-clay and the fused salt (NaCl–$AlCl_3$, molar ratio 1: 1). Among the chlorides of alkali metals used in addition to aluminum chloride, sodium chloride was the most effective. Regarding the effectiveness of metal chlorides, the yield of hydroalkylated products increased in the order of catalytic activity usually found in the alkylation reaction: $AlCl_3>FeCl_3>ZnCl_2$. Such a strong solid acid catalyst as SiO_2–Al_2O_3 modified with hydrofluoric acid, resulted in a rather lower yield than NaCl–$AlCl_3$. Next, we examined the activities of various hydrogenation catalysts in the presence or absence of the fused salt under the same conditions as shown in Table I. As demonstrated in Table II, nickel catalyst gave a poor result for this reaction, even at the reaction temperature of 310°C. In the group VIII triad, palladium in particular gave **3** in good yield in the temperature range from 200°C to 350°C (Fig. 1). The yield of **2** increased linearly with the reaction temperature

Table I. Hydroalkylation of Aniline with Various Alkylation Catalysts and Palladium Catalyst



Alkylation cata. (g)	Temp. (°C)	Time (h)	Yield (%) 2	3	4
—	160	2.5	4.0	4.9	1.8
—	200	2.5	9.4	16.5	4.5
$AlCl_3$ (1.0)	140	2.5	0	0	0
$LiCl-AlCl_3$ (1: 1, 4.0)	180	5.0	3.3	6.4	21.5[a]
$NaCl-AlCl_3$ (1: 1, 4.0)	140	2.5	2.5	0.7	16.0
	180	5.0	8.6	12.7	31.1[a]
$KCl-AlCl_3$ (1: 1, 4.0)	180	5.0	2.5	5.1	18.9[a]
$CsCl-AlCl_3$ (1: 1, 4.0)	180	5.0	10.6	4.0	15.4[a]
$NaCl-FeCl_3$ (1: 1, 4.0)	140	2.5	0.1	0	3.0
$NaCl-ZnCl_2$ (1: 1, 4.0)	140	2.5	0	0	0
10% $HF-SiO_2-Al_2O_3$ (2.0)	140	2.5	0.3	0.2	1.9

Aniline, 30 g; 0.5% $Pd-Al_2O_3$, 1.0 g.
a) 1.0% Pd-clay, 1.0 g.

Table II. Hydrogenation of Aniline with Various Hydrogenation Catalysts in the Presence and Absence of the Fused Salt

Catalyst		Temp. (°C)	Time (h)	Yield (%)		
Hydrogenation cata.	Fused salt			2	3	4
0.5% $Pd-Al_2O_3$	—	240	2.5	20.0	51.9	1.1
	$NaCl-AlCl_3$	240	2.5	9.8	2.8	18.0
0.5% $Rh-Al_2O_3$	—	170	2.5	24.1	3.4	0.1
	$NaCl-AlCl_3$	170	2.5	17.7	28.0	4.3
0.5% $Pt-Al_2O_3$	—	255	2.5	9.8	4.7	3.8
	$NaCl-AlCl_3$	260	2.5	3.1	0.3	3.1
0.5% $Ru-Al_2O_3$	—	170	2.5	80.4	7.0	0.3
	$NaCl-AlCl_3$	170	2.5	18.0	16.7	1.6
Ni	—	170	2.5	9.1	0.7	0.1
	$NaCl-AlCl_3$	310	2.0	0	0	0

Aniline, 30 g; hydrogenation cata., 1.0 g; $NaCl-AlCl_3$ (1: 1), 4.0 g.

while that of 3 decreased gradually after peaking at 220°C. In the presence of the fused salt, hydrogenation on palladium was suppressed to some extent and alkylated aniline was produced. On the other hand, rhodium and ruthenium catalysts gave 2 and 3 as the main products. Based on these results, we conclude that palladium is a specific catalyst for the formation of 4 as a main product. The distribution of the products in the hydroalkylation with $Pd-Al_2O_3$ and the fused salt at various reaction temperatures is also shown in Fig. 2. Hydroalkylation occurred at about 100°C. The yield of 4 and 3 increased with increase in the reaction temperature, and the maximum yield of 4 (30.2%) was attained at 320°C. A further increase in the reaction temperature resulted in a decrease in the yields. However, at reaction temper-

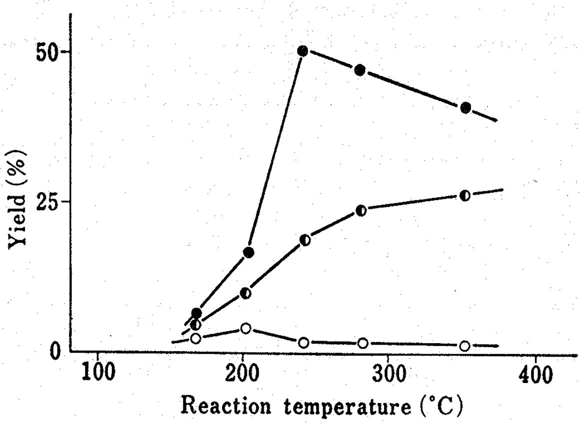


Fig. 1. Relation between the Reaction Temperature and the Yields of Cyclohexylamine and Dicyclohexylamine in the Absence of the Fused Salt

Aniline, 30 g; 0.5% Pd–Al_2O_3, 1.0 g; 2.5 h.
—○— *N*-cyclohexylaniline, —●— dicyclohexylamine, —◐— cyclohexylamine.

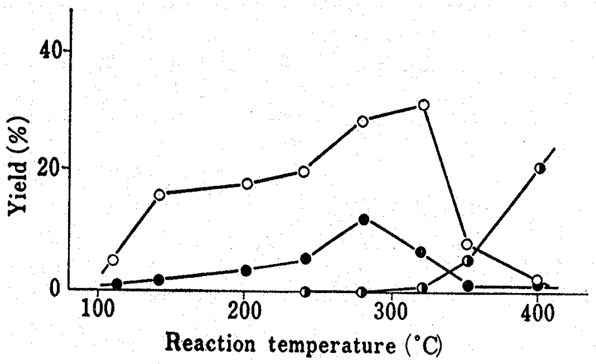


Fig. 2. Relation between the Reaction Temperature and the Yields of *N*-Cyclohexylaniline and Dicyclohexylamine in the Presence of the Fused Salt

Aniline, 30 g; 0.5% Pd–Al_2O_3, 1.0 g; NaCl–$AlCl_3$ (1:1), 4.0 g; 2.5 h.
—○— *N*-cyclohexylaniline, —●— dicyclohexylamine, —◑— diphenylamine+ o-, *p*-cyclohexylaniline.

atures above 300°C, nuclear alkylated aniline, *i.e.*, *o*- and *p*-cyclohexylaniline (**5** and **6**), appeared. At 400°C, the yields of nuclear alkylated products reached 5.4% (**5**) and 7.3% (**6**), and those products were accompanied by diphenylamine (**7**) in 7.6% yield.

2) Reaction Mechanism for the Hydroalkylation of Aniline

We previously reported[2] that the hydroalkylation of benzene proceeds by way of cyclohexene, which is first formed as an intermediate compound on palladium catalyst. Consequently, cyclohexene alkylates benzene on the fused salt. In the case of aniline, no alkylated products were obtained from aniline and cyclohexene in the presence of the fused salt (Table III). This indicates that cyclohexene is an implausible intermediate for the hydroalkylation of aniline. If cyclohexylamine is an intermediate, it can be expected that condensation would occur between aniline and cyclohexylamine to give **4**. When cyclohexylamine, another hypothetical intermediate, was heated at 240°C for 2.5 h with aniline under the same conditions as those for hydroalkylation in the absence of hydrogen, not **4** but **3** was obtained as the main product in the presence of the fused salt or palladium catalyst. This suggests that **3** is formed predominantly by the condensation of two molecules of **2** with liberation of ammonia on the fused salt or palladium catalyst. Therefore, the intermediate in the formation of **4** remains to be identified.

Von Braun[5] suggested that the formation of secondary amines in the hydrogenation of cyanides was due to the interaction between an aldimine and a primary amine. Also,

Table III. Experiments to clarify the Reaction Mechanism

Reactant	Catalyst		Temp. (°C)	Yield (%)	
	Hydrogenation cata.	Fused salt		**3**	**4**
1+cyclohexene	—	NaCl–$AlCl_3$	r.t.	0	0
	—	NaCl–$AlCl_3$	140	0.01	2.3
	0.5% Pd–Al_2O_3	—	180	0	0
1+**2**	0.5% Pd–Al_2O_3	—	240	20.0	6.8
	—	NaCl–$AlCl_3$	240	45.1	2.8
2	—	NaCl–$AlCl_3$	245	59.9	0[a]

Reactant, 0.161 mol; 0.5% Pd–Al_2O_3, 1.0 g; NaCl–$AlCl_3$ (1:1), 4.0 g; 2.5 h.
a) Cyclohexane was the solvent.

Table IV. Rearrangement of *N*-Cyclohexylaniline in the Presence of the Fused Salt

Cata. (g)	Temp. (°C)	Yield (%) 1	4	5	6	7
$NaCl-AlCl_3$ (1)	300	38.5	38.6	3.5	0.9	0
	350	30.5	0.9	11.0	5.3	0
$NaCl-AlCl_3$ (4)	320	12.5	0.9	3.9	16.0	0
0.5% $Pd-Al_2O_3$ (1)	320	3.0	38.6	0	0	6.4

N-Cyclohexylaniline, 8.5 g; cyclohexane, 30 g; 2.5 h.

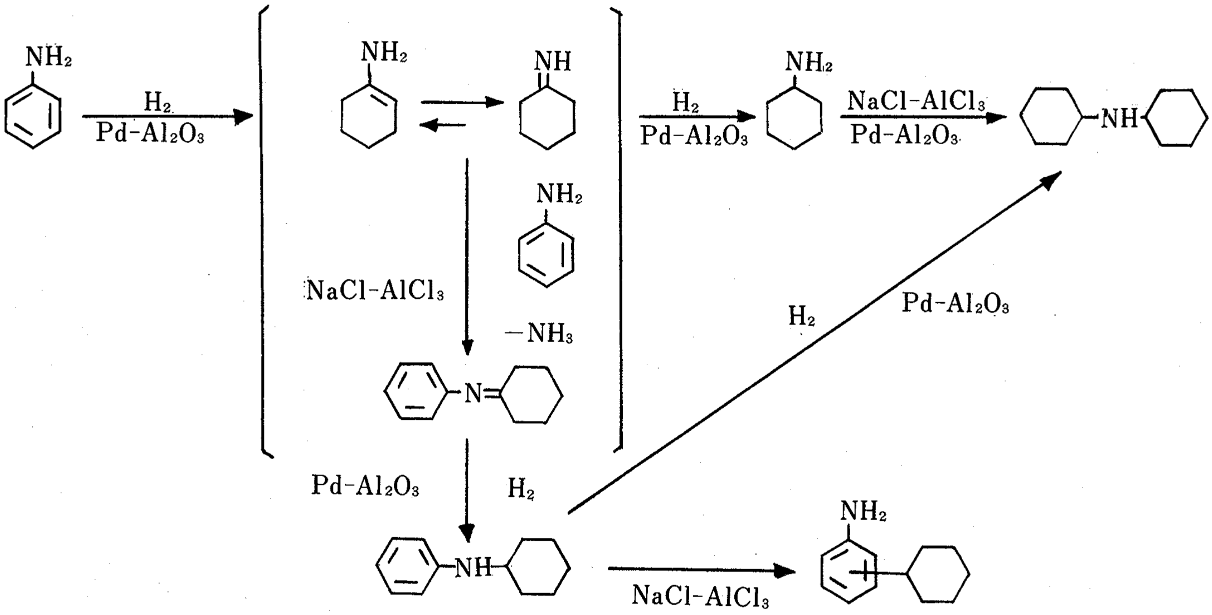


Chart 1

Busch[6] reported that benzalimine reacts with aniline to give benzalaniline by addition reaction, followed by hydrogenation to the corresponding secondary amine. On the other hand, in the hydrogenation of aniline to dicyclohexylamine, Echigoya[7] and Suzuki[8] have isolated *N*-cyclohexylidene-cyclohexylamine as an intermediate, and the formation of this compound is considered to proceed through the condensation of cyclohexylimine and cyclohexylamine. If the formation of **4** proceeds in line with these suggestions, unstable compounds such as cyclohexenylamine or cyclohexylimine may be intermediates for the hydroalkylation of aniline (Chart 1). The next step was the formation of **5** and **6**. In the presence of various acid catalysts, many *N*-substituted arylamines rearrange their alkyl groups to carbon atoms on the phenyl ring.[9] Therefore, we examined the rearrangement of **4** in the presence of the fused salt (Table IV). Upon heating **4** with $NaCl-AlCl_3$ using cyclohexane as a solvent, **5** and **6** were obtained as the main products. These data suggest that **5** and **6** are produced by the rearrangement of **4** which was formed by the hydroalkylation of aniline in the palladium-fused salt system.

Experimental

Nuclear magnetic resonance (NMR) spectra were obtained on a Hitachi R-24B spectrometer at 60 MHz in CCl_4 with tetramethylsilane as an internal standard. Infrared (IR) spectra were recorded on an IR-E spectrometer (Japan Spectroscopic Co., Ltd.). Gas-liquid chromatography (GLC) was run on a Shimadzu GC-3BF gas chromatograph, using a 2 m × 3 mm steel column packed with 20% silicone DC-550 on Shimalite (80—100 mesh). The following abbreviations are used: s=singlet, m=multiplet.

1) **Preparation of Catalysts**——Noble metal catalysts and the fused salt were prepared according to the previously reported method.[2]

2) **General Procedures and Product Analyses**——Aniline and catalysts were placed in a 100 ml stainless steel autoclave (Sakashita Ltd., SUS-32) equipped with a magnetic stirrer. The air in the autoclave was purged and pressurized with hydrogen to 100—150 kg/cm^2 at room temperature. Then, the autoclave was heated to the desired temperature. Products and unreacted aniline were washed with an aqueous solution of sodium hydroxide, and this solution was extracted with ether. The extract was subsequently concentrated by evaporation. Oily products obtained were analyzed by GLC.

Dicyclohexylamine (3)——Aniline (30 g) was hydrogenated with 0.5% Pd–Al_2O_3 (1 g) at 240°C for 2.5 h. The resulting product was purified by distillation *in vacuo* to give **3** (in 51.9% yield), bp 100—103°C (5 mmHg). *Anal.* Calcd for $C_{12}H_{23}N$; C, 79.46; H, 12.97; N, 7.73. Found: C, 75.08; H, 12.33; N, 7.26. IR ν^{neat} cm^{-1}: 3300 (N–H).

***N*-Cyclohexylaniline** (4)——Aniline (30 g) was hydroalkylated with 0.5% Pd–Al_2O_3 (1 g) and the fused salt (NaCl–$AlCl_3$, molar ratio 1: 1, 4 g) at 140°C for 2.5 h. The resulting product was isolated by distillation *in vacuo* to give **4** (in 35.6% yield), bp 114—115°C (5 mmHg). *Anal.* Calcd for $C_{12}H_{17}N$: C, 82.23; H, 9.78; N, 7.99. Found: C, 81.00; H, 9.85; N, 7.70. NMR (CCl_4) δ: 0.96—2.01 (11H, m); 3.2 (1H, s); 6.10—7.32 (5H, m, aromatic proton). IR ν^{neat} cm^{-1}: 3400 (N–H); 1603 (C–H).

***o*-Cyclohexylaniline** (5), ***p*-Cyclohexylaniline** (6) **and Diphenylamine** (7)——Aniline (30 g) was hydroalkylated with 0.5% Pd–Al_2O_3 (1 g) and the fused salt (4 g) at 400°C for 2.5 h. Fractionation of the product gave unreacted aniline, **3**, **4** and a high-boiling residue containing **5**, **6** and **7**. These products were separated by a gas chromatography fractionation technique. The yields of **5**, **6** and **7** were 5.4, 7.3 and 7.6%, respectively. *o*- and *p*-Isomers were identified by comparison of their NMR spectra with those of *o*-toluidine and *p*-toluidine, respectively. **5**: *Anal.* Calcd for $C_{12}H_{17}N$: C, 82.23; H, 9.78; N, 7.99. Found: C, 82.23; H, 9.71; N, 7.76. NMR (CCl_4) δ: 1.1—2.4 (11H, m); 3.5 (2H, s); 6.5—7.1 (4H, m, aromatic proton). IR $\nu_{\text{max}}^{\text{neat}}$ cm^{-1}: 1603 (C–H). **6**: *Anal.* Calcd for $C_{12}H_{17}N$: C, 82.23; H, 9.78; N, 7.99. Found: C, 82.16; H, 9.70, N, 7.79. NMR (CCl_4) δ: 1.2—2.5 (11H, m); 3.5 (2H, s); 6.4—7.1 (4H, m, aromatic proton). IR $\nu_{\text{max}}^{\text{neat}}$ cm^{-1}: 1600 (C–H). **7**: *Anal.* Calcd for $C_{17}H_{11}N$: C, 85.17; H, 6.55; N, 8.23. Found: C, 85.05; H, 6.79; N, 8.13. NMR (CCl_4) δ: 5.5 (1H, m); 6.8—7.5 (10H, m, aromatic proton). IR ν^{neat} cm^{-1}: 1600 (C–H). mp 49.5°C.

Acknowledgement We are grateful to Dr. Mineo Shimizu for helpful discussions.

References and Notes

1) T. Kamiyama, S. Enomoto and M. Inoue, *Chem. Lett.*, **1979**, 261.
2) T. Kamiyama, S. Enomoto and M. Inoue, *Chem. Pharm. Bull.*, **29**, 15 (1981).
3) H. Adkins and H.I. Cramer, *J. Am. Chem. Soc.*, **52**, 4349 (1930).
4) T.S. Carwell and H.L. Morrill, *Ind. Eng. Chem.*, **29**, 1247 (1937).
5) J.v. Braun, *Ber.*, **56**, 1988 (1923).
6) M. Busch, *Ber.*, **29**, 2143 (1896).
7) H. Hagihara and E. Echigoya, *Bull. Chem. Soc. Jpn.*, **38**, 2094 (1965).
8) K. Ikedate, T. Suzuki and S. Suzuki, *Nippon Kagaku Zasshi*, **89**, 304 (1968).
9) J. Reilly and W.J. Hickenbottom, *J. Chem. Soc.*, **117**, 103 (1920).