Table II. Results and Some Properties of Dihydropyridotriazines

	Reactant		Yield,		Ir (KBr), cm^{-1}	
Compd^a	*N*-Imine	Azirine	%	Mp, °C	NH	C=C or C=N
6	**2**	**1**	73	95–97	3225	1637
7	**3**	**1**	65	112–115	3240	1654
8	**4**	**1**	59	127–131	3260	1622
9	**5**	**1**	32	131–135	3238	1627
13	**10**	**1**	27		3260^b	1637^b
14	**11**	**1**	90	126–129	3248	1636
15	**12**	**1**	72	152–154	3250	1633
20 + 21	**16**	**1**	54	*c*	3200	1642
22	**17**	**1**	78	170–172	3270	1635
23	**18**	**1**	90	134–137	3240	1632
24	**19**	**1**	84	160	3224	1624
28	**26**	**25**	90	185–188	3260	1637
29	**27**	**25**	93	161–164	3270	1620

[a] **6.** Anal. Calcd for $C_{13}H_{13}N_3$: C, 73.90; H, 6.20; N, 19.89. Found: C, 73.93; H, 6.22; N, 19.73. **7.** Calcd for $C_{14}H_{15}N_3$: C, 74.64; H, 6.71; N, 18.65. Found: C, 74.57; H, 6.69; N, 18.62. **8.** Calcd for $C_{14}H_{12}N_4$: C, 71.16; H, 5.12; N, 23.72. Found: C, 70.87; H, 5.03; N, 23.81. **9.** Calcd for $C_{15}H_{15}N_3O_2$: C, 66.90; H, 5.61; N, 15.61. Found: C, 66.88; H, 5.45; N, 15.67. **14.** Calcd for $C_{17}H_{15}N_3$: C, 78.13; H, 5.79; N, 16.08. Found: C, 78.03; H, 5.87; N, 15.92. **15.** Calcd for $C_{18}H_{17}N_3$: C, 78.51; H, 6.22; N. 15.26. Found: C, 78.22; H, 6.17; N, 15.41. **20 + 21.** Calcd for $C_{14}H_{15}N_3$: C, 74.64; H, 6.71; N, 18.65. Found: C, 74.63; H, 6.75; N, 18.44. **22.** Calcd for $C_{14}H_{12}N_4$: C, 71.16; H, 5.12; N, 23.72. Found: C, 70.86; H, 5.08; N, 23.85. **23.** Calcd for $C_{15}H_{15}N_3O_2$: C, 66.90; H, 5.61; N, 15.61. Found: C, 66.82; H, 5.34; N, 15.56. **24.** Calcd for $C_{17}H_{15}N_3$: C, 78.13; H, 5.79; N, 16.08. Found: C, 78.14; H, 5.83; N, 15.89. **28.** Calcd for $C_{23}H_{19}N_3$: C, 81.87; H, 5.68; N, 12.45. Found: C, 81.61; H, 5.83; N, 12.58. **29.** Calcd for $C_{23}H_{19}N_3$: C, 81.87; H, 5.68; N, 12.45. Found: C, 81.59; H, 5.58; N, 12.35. [b] Neat. [c] Mixture.

Registry No.—**1,** 7654-06-0; **2,** 6295-87-0; **3,** 7583-92-8; **4,** 39996-45-7; **5,** 59247-63-1; **6,** 54855-55-9; **7,** 54855-56-0; **8,** 59247-64-2; **9,** 59065-85-9; **10,** 7583-90-6; **11,** 39996-55-9; **12,** 39996-56-0; **13,** 59065-81-5; **14,** 59065-86-0; **15,** 59065-87-1; **16,** 7583-91-7; **17,** 39996-44-6; **18,** 56000-42-1; **19,** 39996-57-1; **20,** 59065-82-6; **21,** 59065-78-0; **22,** 59065-83-7; **23,** 59065-84-8; **24,** 59247-65-3; **25,** 16483-98-0; **26,** 7184-52-3; **27,** 31436-50-7; **28,** 59247-66-4; **29,** 59247-67-5; **30,** 26370-56-9.

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Oxidation of Primary Amines and Indoline with Palladium Dichloride and Gold Trichloride

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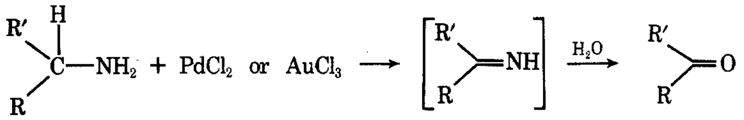
Primary amines were oxidized in water by $PdCl_2$ and $AuCl_3$ with isolated product yields of 2.5–72% depending on reaction pH and structure of the amine. The oxidation of indoline to indole gave isolated yields of 0–83% depending on reaction conditions, with the optimum reaction in methanol and triethylamine at room temperature.

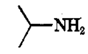
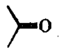
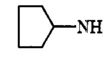
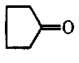
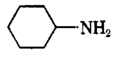
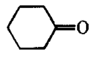
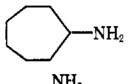
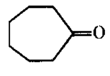
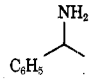
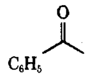
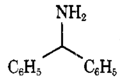
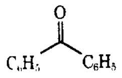
In contrast to the oxidation of alcohols with palladium dichloride, the far less universal oxidation of amines to carbonyl compounds has not been previously explored with this reagent. Alcohols are found to undergo 50–100% conversions to carbonyl compounds with palladium dichloride.[2–4] In these oxidations, yields are sometimes greater than 100%, based on the amount of palladium dichloride used, because of a catalytic dehydrogenation effect of the generated metallic palladium.[3] Oxidations of alcohols can also be achieved with catalytic amounts of palladium dichloride under 3 atm of oxygen in the presence of cupric chloride or nitrate.[4]

Oxidations of tetrahydroquinoline to quinoline in 102% yield and of tetrahydroisoquinoline to isoquinoline in 130% yields (based on $PdCl_2$) again indicate a catalytic dehydrogenation by the generated palladium metal. In a corollary study heating of primary or secondary amines over metallic palladium led to more highly N-alkylated products.[5] Successive dehydrogenation, condensation, and hydrogenation steps were postulated for these reactions. The dehydrogenation of indoline to indole at 100–150 °C over a palladium on charcoal catalyst again demonstrates this reaction.[6]

A comparison of the half-wave potential for Pd^{2+} to Pd^0 (E^0

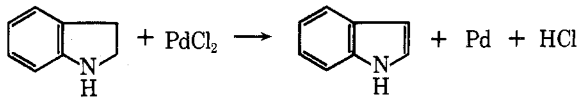
Table I. Oxidation of Primary Amines with Palladium Dichloride and Gold Trichloride



Amine[e]	Product	Isolated yield, %	
		$PdCl_2$	$HAuCl_4$
		52^a	23 (pH 1)^{a,d} 72 (pH 5.8)^{c,d}
		$2.5,^{a,d}$ $11^{b,d}$	9 (pH 4.5)^{c,d}
		$6.4^{a,d}$	0 (pH 1)^a 60 (pH 5.3)^c 50 (pH 6.8)^c
		57^a	52 (pH 4.5)^c 36 (pH 6.2)^c
		$21,^a$ 54^b	20 (pH 1)^{a,d} 29 (pH 6)^{c,d}
		Trace^a	48 (pH 4.5)^c
C_6H_5—CH_2NH_2	C_6H_5—CHO	27^a	
C_6H_5—$CH_2CH_2NH_2$	C_6H_5—CH_2CHO	19^a	10 (pH 5.8)^c
	C_6H_5—CH_2CO_2H		30 (pH 5.8)^c

[a] Product of 1 equiv of oxidizing agent in water (method a). [b] Addition of 10% Pd/C catalyst to reaction mixture (method b). [c] Adjustment of initial pH with NaOH (method c). [d] Isolated as 2,4-dinitrophenylhydrazone. [e] Registry no. are, respectively, 75-31-0, 1003-03-8, 108-91-8, 5452-35-7, 98-84-0, 91-00-9, 100-46-9, 64-04-0.

Table II. Oxidation of Indoline to Indole with $PdCl_2$



Reactant	Conditions[a]	Yield, %
Indoline lithium salt[b]	THF, 0 °C	42
Indoline lithium salt	THF–TEA, r.t.	68
Indoline Pd salt (no $PdCl_2$)[c]	H_2O–NaOH, reflux	37
Indoline[d]	Methanol–TEA, r.t.	83
Indoline	TEA, r.t.	Trace
Indoline	THF, r.t.	0
Indoline	H_2O–HCl, steam dist	70
Indoline	H_2O–HCl, 10% Pd/C, r.t.	27
Indoline (no $PdCl_2$)	H_2O–HCl, 10% Pd/C, reflux	13

[a] THF = tetrahydrofuran, TEA = triethylamine. [b] Registry no., 59092-48-7. [c] Registry no., 59092-49-8. [d] Registry no., 496-15-1.

= 0.99) with those for Au^{3+} and Au^+ to Au^0 ($E^0 = 1.50$ and 1.68)[7] suggests that gold salts should be even more powerful oxidizing agents for amines. However, they have apparently not been explored as reagents in organic synthesis.[8] Although the formation of metallic gold from reactions of gold trichloride with amino acids,[9] piperidine, toluidine, and naphthylamine[10] was reported and the formation[10,11] and kinetics of substitution reactions[12,13] of gold amine complexes are known, the organic products or yields of these amine oxidations were not given. Metallic gold has also been used for catalytic dehydrogenations, but it seems to be less effective than palladium in this respect.

Oxidations of the primary amines shown in Table I with $PdCl_2$ or $HAuCl_4$ were achieved by combining the amine and oxidizing agent in water and distilling the reaction mixture to dryness (method a). The steam distilled carbonyl compounds thus formed by hydrolysis of initial imine products were quantitatively characterized by isolation, dinitrophenylhydrazone formation, and gas chromatography. Since a catalytic effect of palladium metal was anticipated, 10% palladium on charcoal was added to the reaction mixture of cyclopentyl- and α-phenethylamines, with a resultant multiplication of yields (method b). It may be noted that in absence of $PdCl_2$ the palladium on charcoal did not give any oxidation of cyclopentylamine, cyclohexylamine, or β-phenethylamine but that low-yield oxidations of α-phenethylamine to acetophenone and of indoline to indole could be seen under those conditions.

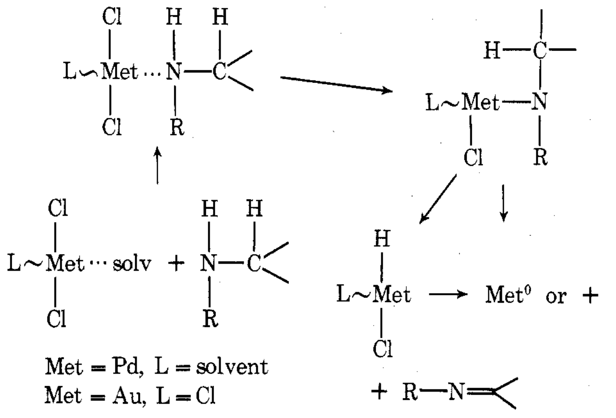
It has been shown that aqueous solutions of chloroauric acid at a pH near 1 contain gold coordinated primarily as $AuCl_4^-$, at pH 4 as $AuCl_3OH^-$, at pH 5.5 as $AuCl_2(OH)_2^-$, at pH 7 as $AuCl(OH)_3^-$ with Au_2O_3 precipitating at a pH above 7.[14] Thus it was of interest to study the amine oxidations with an adjustment of the initial pH of the reaction mixtures (method c). Highest yields were invariably found in weakly acidic solutions. These results may reflect an optimum gold–amine coordination or alternatively optimum conditions for balancing amine complexation and imine product dissociation and hydrolysis.

The formation of aldehydes or ketones by oxidation of secondary amines with $PdCl_2$ or $AuCl_3$ was less successful. Thus di-*n*-butylamine gave only traces of butyraldehyde with $PdCl_2$, diethylamine produced a 7.2% yield of acetaldehyde when oxidized with $HAuCl_4$, and *N*-phenylcyclohexylamine yielded no cyclohexanone with the latter reagent at pH 6.

However, indoline was readily oxidized to indole by $PdCl_2$. Yields corresponding to various reaction conditions are shown in Table II. The most successful indoline oxidation was found to be one in which triethylamine had been added. Since indole rather than a more basic imine is formed in this reaction (in contrast to the preceeding amine oxidations) neutralization of the generated hydrochloric acid is required.

From attempted oxidations of indoline with $AuCl_3$ at pH 1 or 4, very little indole could be isolated.

As amine complexes of palladium and gold have been characterized,[11-13,15] and palladium amides are well known,[15] one may assume that the present amine oxidations proceed at least through the first, and possibly both of these intermediates, depending on pH. Subsequent imine formation may then take place either by direct generation of Pd^0 or Au^+ or through metal hydride intermediates[2,3,16] and their subsequent decomposition. The formation of metallic gold requires an additional disproportionation or amine redox reaction or the formation of larger amine complexes (3:2 amine:$AuCl_3$).



Experimental Section

General. Many of the palladium dichloride reactions reported in this section were performed by a general procedure. The palladium dichloride was dissolved in water containing a small amount of hydrochloric acid and the amine was added. The reaction mixture was then heated and distilled rapidly to dryness at atmospheric pressure. Where the expected product was a low molecular weight ketone or aldehyde, the distillate was collected in a receiving flask containing 2,4-dinitrophenylhydrazine reagent. The higher molecular weight ketones were extracted from the aqueous distillate with ether using a liquid–liquid extractor or with dichloromethane. The organic extract was then dried and condensed yielding the product which was analyzed either as the pure compound or its 2,4-DNP derivative. The following oxidations of isopropylamine and α-methylbenzylamine are representative of the general method used. Other reactions performed under similar conditions are given in abbreviated form. Reactions which were not performed by this general procedure are described fully. All of these reactions were performed under a nitrogen atmosphere.

Reaction of Isopropylamine with Palladium Dichloride. Palladium dichloride (0.3 g, 1.7 mmol) was dissolved in 25 ml of water containing enough hydrochloric acid to maintain complete solution. Freshly distilled isopropylamine (0.5 g, 8.5 mmol) was added and the solution was distilled to a paste into a receiving flask containing 15 ml of saturated 2,4-DNP reagent. The precipitate was filtered, recrystallized once from ethanol, and dried yielding a yellow hydrazone (0.21 g, 52%) which was identified as acetone 2,4-DNP by TLC and mixture melting point comparison with an authentic sample (mp 124–125 °C, lit.[15] 125–126 °C).

Reaction of α-Methylbenzylamine with Palladium Dichloride and Palladium Metal. Palladium dichloride (0.19 g, 1.07 mmol), α-methylbenzylamine (0.20 g, 1.65 mmol), and 10% palladium on carbon (0.4 g, 0.38 mg-atom) were mixed in 105 ml of water containing a few drops of hydrochloric acid and the contents were distilled to dryness. The distillation apparatus was rinsed with dichloromethane and the distillate was extracted several times with dichloromethane. The organic extracts and washings were combined, dried, and concentrated, yielding a colorless oil (0.07 g, 54%) which gave a single spot on the TLC and which was identified as acetophenone by TLC, ir (1680 cm^{-1}), and mixture melting point of the 2,4-DNP derivative with an authentic sample. A 21% yield was obtained in the absence of palladium on carbon.

Reaction of α-Methylbenzylamine with Palladium Metal. α-Methylbenzylamine (0.09 g, 0.76 mmol) was added to 7 ml of water and the mixture was adjusted to a pH of approximately 5 with 10% hydrochloric acid. To this solution was added 10% palladium on carbon (0.14 g, 0.13 mg-atom) and the mixture was heated at reflux for 28 h. The mixture was then cooled, filtered through Celite, and extracted several times with dichloromethane. The combined organic extracts were dried, filtered, and evaporated, yielding a clear oil (0.11 g, 12%) which was essentially pure by TLC and VPC. The material was identified as acetophenone as described above.

Reaction of Cyclopentylamine with Palladium Dichloride and Palladium Metal. Palladium dichloride (0.35 g, 2.0 mmol), cyclopentylamine (0.12 g, 1.4 mmol), 10% palladium on carbon (0.4 g, 0.38 mg-atom), and 20 ml of water yielded cyclopentanone which was isolated as the 2,4-dinitrophenylhydrazone. The 2,4-DNP derivative was purified by dry column chromatography on 100 g of Woelm activity grade III silica gel eluted with benzene yielding the pure compound (0.04 g, 11%), mp 142–143 °C (lit.[16] 142 °C). A 2.5% yield was obtained without palladium metal. (No cyclopentanone was formed from cyclopentylamine and 10% palladium on charcoal, refluxed at pH 4.0 for 24 h in water.)

Reaction of Cyclohexylamine with Palladium Dichloride and Palladium Metal (b). Palladium dichloride (0.44 g, 2.26 mmol), cyclohexylamine (0.24 g, 2.4 mmol), 10% palladium on carbon (0.64 g, 0.60 mg-atom), and 10 ml of water were distilled in the usual way. This yielded cyclohexanone (0.04 g, 6.4%) isolated as its 2,4-DNP derivative, mp 158–159 °C (lit.[16] 160 °C). No cyclohexanone was formed in the absence of either palladium reagent.

Reaction of Cycloheptylamine with Palladium Dichloride. Cycloheptylamine (0.20 g, 1.77 mmol) and palladium dichloride (0.29 g, 1.63 mmol) gave cycloheptanone (0.11 g, 57%) isolated as the pure compound, mp 2,4-DNP derivative 147–148 °C (lit.[17] 148 °C).

Reaction of Benzylamine with Palladium Dichloride. Palladium dichloride (0.40 g, 2.3 mmol), benzylamine (0.18 g, 1.7 mmol), and 25 ml of water gave benzaldehyde (0.05 g, 27%) isolated as the pure compound, mp 2,4-DNP derivative 239–240 °C (lit.[15] 239–240 °C).

Reaction of β-Phenylethylamine with Palladium Dichloride and Palladium Metal. Palladium dichloride (0.37 g, 2.1 mmol), β-phenylethylamine (0.27 g, 2.2 mmol), 10% palladium on carbon (0.41 g, 0.4 mg-atom), and 100 ml of water yielded phenylacetaldehyde (0.05 g, 19%) isolated as the pure compound, mp 2,4-DNP derivative 110–111 °C (lit.[17] 110 °C).

Reaction of Amines with Gold Trichloride. General. Many of the reactions of amines with gold trichloride described in this section were performed by the same general procedure. The amine and chloroauric acid were combined in water and in some cases the pH was then adjusted by addition of 10% sodium hydroxide. The mixture was then heated and distilled to dryness. For low molecular weight ketones or aldehydes the distillate was collected directly into 2,4-dinitrophenylhydrazine reagent and the yield determined from the resulting hydrazone. Higher boiling products were usually isolated in pure form. The oxidation of isopropylamine is representative of the procedure used. Those reactions which were not performed by this general method are described in greater detail. The percentage yields reported in this section are based on the amount of carbonyl compound formed according to the equation 3amine + $2AuCl_3$ + $3H_2O$ = 3carbonyl + $2Au^0$ + 6HCl + $3NH_3$

Preparation of Chloroauric Acid Trihydrate (CAT). Gold powder (1.00 g, 5.08 mg-atoms) was dissolved in 8.0 ml of aqua regia prepared from nitric acid (2.0 ml), hydrochloric acid (4.0 ml), and water (2 ml). The solution was evaporated to dryness on a steam bath and 2 ml of hydrochloric acid was added. The solution was again evaporated to dryness and a second portion of hydrochloric acid was added and evaporated. The addition of hydrochloric acid was repeated again but the evaporation was stopped before complete dryness was obtained. The yellow paste was placed in a vacuum desiccator and dried at approximately 10 mm over phosphorus pentoxide for 48 h, yielding chloroauric acid trihydrate (2.01 g, 100%).

Recovery of Gold from Reaction Mixtures. All reaction vessels and filtering apparatus were washed with aqua regia and all extracts, filter paper, and drying reagents were added. The solution was evaporated to dryness and water was added. The solution was filtered and the pH was adjusted to approximately 2 with sodium hydroxide. A saturated sodium nitrite solution (40 ml) was added in several portions and the solution was heated to boiling. The pH was then adjusted to approximately 8 with sodium hydroxide and the mixture cooled and filtered. The material which collected on the filter was washed with 10% hydrochloric acid until the wash water was colorless and then rinsed with ethanol and ether. The gold remaining accounted for approximately 86% of the gold used. This gold was used without further treatment in the formation of new gold chloride reagent.

Reaction of Isopropylamine with Gold Trichloride. A. Chloroauric acid trihydrate (0.20 g, 0.51 mmol) and isopropylamine (0.07 g, 1.2 mmol) were dissolved in 20 ml of water and the pH was adjusted to 5.8 with 10% sodium hydroxide. The mixture was then distilled to dryness under a nitrogen atmosphere and the distillate was collected in a receiving flask containing 2,4-DNP reagent. The yellow precipitate was filtered and dried yielding acetone-2,4-dinitrophenylhydrazone (0.13 g, 72%), mp 124–125 °C.

B. CAT (0.19 g, 0.48 mmol) and isopropylamine (0.10 g, 1.7 mmol) were dissolved in 20 ml of water and distilled into 2,4-DNP reagent yielding acetone 2,4-dinitrophenylhydrazone (0.04 g, 23%).

Reaction of Cyclopentylamine with Gold Trichloride. CAT (0.168 g, 0.42 mmol) and cyclopentylamine (0.12 g, 1.4 mmol) were combined in 20 ml of water at a pH of 4.3–4.5 and distilled into 2,4-DNP reagent yielding the hydrazone of cyclopentanone (0.015 g, 9%), mp 139–141 °C.

Reaction of Cyclohexylamine with Gold Trichloride. A. CAT (0.21 g, 0.53 mmol) and cyclohexylamine (0.08 g, 0.81 mmol) in 25 ml of water at a pH of 5.3 yielded pure cyclohexanone (0.45 g, 60%) after 24 h continuous extraction of the distillate with ether.

B. A 50% yield was obtained at pH 6.8.

C. CAT (0.30 g, 0.76 mmol) and cyclohexylamine (0.99 g, 0.91 mmol) in 25 ml of water at a pH of 0.9–1.1 gave no product which formed a precipitate with 2,4-DNP reagent or which corresponded to cyclohexanone by TLC.

Reaction of Cycloheptylamine with Gold Trichloride. A. CAT (0.338 g, 0.85 mmol) and cycloheptylamine (0.09 g, 0.8 mmol) in 30 ml of water at a pH of 6.0–6.2 yielded a colorless oil (0.083 g) which was distilled at 90–110 °C (8–10 mm) to give cycloheptanone (0.032 g, 36%).

B. CAT (0.133 g, 0.34 mmol) and cycloheptylamine (0.16 g, 1.4 mmol) in 20 ml of water at a pH of 4.5 yielded cycloheptanone (0.03 g, 52%).

Reaction of α-Methylbenzylamine with Gold Trichloride. A. CAT (0.30 g, 0.77 mmol) and α-methylbenzylamine (0.16 g, 1.3 mmol) in 25 ml of water were distilled into 2,4-DNP reagent to yield the 2,4-DNP derivative of acetophenone (0.069 g, 20%).

B. CAT (0.28 g, 0.71 mmol), α-methylbenzylamine (0.10 g, 0.83 mmol), and sodium carbonate (0.1 g, 0.94 mmol) in 22 ml of acetonitrile gave after 1 h a complex mixture of products. At least seven new volatile components were observed by VPC. One of these appeared to be acetophenone by retention time on TLC and VPC when compared with an authentic sample. Saturated sodium chloride solution (10 ml) was added to this solution and the mixture was extracted with benzene. The benzene extracts were dried and evaporated yielding a brown residue. This residue was treated with 2,4-DNP reagent and filtered yielding after one further recrystallization the hydrazone of acetophenone (0.017 g, 7%).

C. CAT (0.19 g, 0.48 mmol) and α-methylbenzylamine (0.13 g, 1.1 mmol) in 20 ml of water at a pH of 6.0 gave acetophenone (0.062 g, 29%) isolated as the 2,4-DNP derivative.

Reaction of Diethylamine with Gold Trichloride. CAT (0.19 g, 0.48 mmol) and diethylamine (0.07 g, 0.96 mmol) in 25 ml of water were distilled into 2,4-DNP reagent yielding a yellow solid which was recrystallized to give the hydrazone of acetaldehyde (0.014 g, 7.2%).

Reaction of β-Phenylethylamine with Gold Trichloride. CAT (0.32 g, 0.81 mmol) and β-phenylethylamine (0.10 g, 0.83 mmol) in 20 ml of water at a pH of 5.8 gave a mixture of phenylacetaldehyde and phenylacetic acid which were identified by TLC and VPC comparison with authentic samples. The colorless oil (0.04 g, ca. 40%) appeared by VPC and by the relative intensities of the carbonyl peaks in the ir spectrum to be approximately 25% aldehyde and 75% acid.

Reaction of Benzhydrolamine with Gold Trichloride. CAT (0.13 g, 0.35 mmol), benzhydrolamine (0.10 g, 0.55 mmol), and 6 ml of tetrahydrofuran were combined with 2 ml of water at a pH of 4.5–5.0 and stirred for 12 h. Ether (20 ml) was added and the solution was washed with 2 ml of 10% sodium hydroxide followed by two 2-ml portions of 5% hydrochloric acid. The organic layer was dried over magnesium sulfate, filtered, and concentrated to a colorless residue (0.080 g). TLC analysis on silica gel eluted with benzene indicated two products at R_f values of 0.41 and 0.55, respectively, and a third spot which did not move from the origin. This material was chromatographed on Woelm neutral alumina activity grade I eluted with benzene. Separation was not adequate to isolate pure compounds directly from the column. The second fraction contained a colorless oil which corresponded to the material at R_f value of 0.41 and was identified as benzophenone after recrystallization from ethanol by ir and mixture melting point comparison with an authentic sample. The first fraction contained the material with R_f 0.55 as well as some benzophenone. This material was distilled at 100–140 °C (0.001 mm) and recrystallized from benzene–ethanol yielding white crystals which were identified as benzophenonylidene benzhydrolamine, mp 153–154 °C,[18] by mixture melting melting point, ir, and mass spectra comparison with an authentic sample.

The yields of benzophenone and benzophenylidene benzhydrolamine in the total reaction mixture were determined by quantitative thin layer chromatography.[19] Thus, the reaction products (0.080 g) contained benzophenone (0.021 g, 25%) and benzophenonylidene benzhydrolamine (0.023 g, 15%). These values are the average of several experiments and are reproducible to within 5%. The total yield of benzophenone both isolated and as the Schiff base derivative was 0.033 g (48% based on gold trichloride).

Reaction of Indoline with Palladium Dichloride. A. As Lithium Salt. Indoline (0.12 g, 1.0 mmol) was treated in an addition funnel with *n*-butyllithium (0.5 ml, 1.0 mmol) in 2 ml of tetrahydrofuran. This solution was added slowly, under nitrogen, to a stirred solution of palladium dichloride (0.18 g, 1.0 mmol) in 2 ml of tetrahydrofuran which was cooled to 0 °C. A black precipitate formed immediately and after 10 min the reaction mixture was filtered through Celite, washed with 5% hydrochloric acid, and concentrated. The residue was chromatographed on a 30 × 1.5 cm silica gel column and eluted with 20% ether in benzene. After removal of 100 ml of solvent the next 200 ml contained indole (0.05 g, 42%).

B. With Triethylamine. Addition of 1 ml of triethylamine to this reaction mixture and stirring for 2 h at room temperature gave 0.08 g (68% yield).

C. Isolation of Pd Salt. Indoline (0.39 g, 3.2 mmol) and palladium dichloride (0.29 g, 1.61 mmol) were combined in 25 ml of chloroform. The solution was heated to reflux for 3 h and distilled to dryness at reduced pressure leaving a yellow-orange solid. This solid was treated with 25 ml of water and 5 ml of 10% sodium hydroxide under reflux for 5 min. The mixture was neutralized with hydrochloric acid, extracted with dichloromethane, and chromatographed on a 40 × 2.5 cm dry column of Woelm activity grade III silica gel eluted with ether. The indole portion was removed and extracted with ethanol, yielding indole (0.07 g, 37%).

D. In Methanol–Triethylamine. indoline (0.12 g, 1.0 mmol), palladium dichloride (0.18 g, 1.0 mmol), and triethylamine (0.1 g, 1.0 mmol) were dissolved in 3 ml of methanol and allowed to stir under nitrogen for 2 h during which time a black precipitate of palladium metal formed. The mixture was filtered through Celite, 5 ml of 10% hydrochloric acid was added, and the solution was saturated with sodium chloride and extracted with benzene. The benzene extracts were dried and evaporated yielding indole (0.10 g, 83%).

An analogous reaction mixture without triethylamine in tetrahydrofuran showed no indole after 3 days at room temperature and precipitation of Pd metal. A reaction in triethylamine for 24 hr at room temperature gave traces of indole identified by TLC and other unidentified products.

E. In Water. Indoline (0.29 g, 2.4 mmol) was added to 20 ml of water and enough 10% hydrochloric acid was added to make the solution homogeneous. Palladium dichloride (0.21 g, 1.2 mmol) was added and the reaction vessel was equipped with a short path distillation column. The flask was then heated and the reaction mixture distilled to dryness under a nitrogen atmosphere. Indole azeotroped with water and crystallized in the distillate. The distillate was neutralized with sodium carbonate and extracted with dichloromethane. The extracts were dried and evaporated yielding indole (0.10 g, 70%).

F. Palladium on Carbon Added. Indoline (0.34 g, 2.8 mmol), palladium dichloride (0.26 g, 1.47 mmol), and 10% palladium on carbon (0.10 g, 0.1 mg-atom) were combined in 30 ml of water to which enough hydrochloric acid had been added to dissolve the amine. The reaction mixture was allowed to stir for 16 h, filtered, and extracted with dichloromethane. The organic extracts were evaporated and the residue was chromatographed by preparative TLC on a Mallinckrodt ChromAR 1000 sheet eluted with benzene. The indole-containing portion was removed, extracted with ethanol, and concentrated to yield indole (0.05 g, 27%).

G. Reaction with Palladium on Carbon. Indoline (0.18 g, 1.5 mmol) was dissolved in 3 ml of water containing hydrochloric acid and the pH was adjusted to approximately 2. Palladium on carbon (0.3 g, 0.3 mg-atom) was added and the mixture was refluxed under nitrogen for 24 h. The mixture was then filtered, extracted with benzene, and treated with picric acid yielding indole picrate, 0.07 g (12% yield).

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Registry No.—Diethylamine, 109-89-7; triethylamine, 121-44-8; palladium dichloride, 7647-10-1; gold trichloride, 13453-07-1.

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London Force and Related Coulombic Interactions in the Displacement Reaction with Substituted Benzyl Chlorides

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The reaction rate constants for the displacement reactions with ortho- and para-substituted benzyl chlorides (CH_3, Cl, Br, and I) and the nucleophiles, MeO^-, PhS^-, and I^-, are presented. After accounting for the electrical effects of the substituents, all the trends in the values of the k_o:k_p rate ratios are best explained by considering two opposing factors operating in the transition state structure, steric effects, and London and related coulombic interactions between the nucleophiles and the ortho substituents.

London forces and related coulombic interactions have long been recognized as factors affecting equilibria and reaction rates.[1] Bunnett,[2] in a theoretical paper, suggested the operation of London forces in several bimolecular nucleophilic reaction series. He attributed the enhancement of reaction rate to London forces when the transition state structure is such as to bring highly polarizable groups close to one another. Bunnett and Reinheimer[3] estimated these forces in the reaction of the *o*-bromo- and *o*-methylbenzyl chlorides with the nucleophiles, MeO^-, PhS^-, and I^-. Sisti,[4] simultaneously with Reinheimer,[5] offered a new method of comparing the rates from that of Bunnett.[3] Reinheimer[5] examined the *o*-CH_3:*p*-CH_3 and *o*-Br:*p*-Br reaction rate ratios of benzyl chlorides with the same nucleophiles and obtained a better correlation of theory and experimental results than Bunnett.[3] He demonstrated that calculations of the magnitude of London forces operating in the transition state indicated that the differences in the rate ratios with MeO^-, PhS^-, and I^- for a given substituent may be assigned to these forces. However, it was pointed out by Sisti[4] that comparison of the *o*-CH_3:*p*-CH_3 and *o*-Br:*p*-Br rate ratios with any given nucleophile did not show the trends expected from London interactions alone, i.e., charged nucleophiles invariably gave higher ortho:para rate ratios with the less polarizable methyl group than with the more polarizable bromo group.

This paper reports the results of studies of the reaction of the nucleophiles MeO^-, PhS^-, and I^- with other ortho- and para-substituted benzyl chlorides. The purpose of the study was to determine if the trends still persist in the rate ratios and to discuss their possible origins.

Results

The reaction rate constants for the nucleophilic displacement of chloride from the ortho- and para-substituted benzyl chlorides are presented in Table I. Comparison of the results with the literature shows moderate to good agreement. Some comparisons are presented in Table I. We have confidence in our results since VPC analysis of the benzyl chlorides indicated that they were at least 99%pure. Also, the reaction rates of the nucleophiles with benzyl chloride were measured and only when found to be in acceptable agreement with the literature values were the analytical methods applied to the kinetic determinations for the substituted benzyl chlorides. The observed rate constants for the lithium methoxide runs are composites of the methoxide and solvolysis reactions. Thus, the rate constants presented in Table I are those which have been corrected for solvolysis by the method of Bunnett.[3]

Discussion

It will first be demonstrated that the trends in the k_o:k_p values (Table II) for a given ortho substituent with different nucleophiles and for any given nucleophile with different ortho substituents cannot be explained from consideration of the polar and steric effects of the substituents. A new consideration will be suggested which can, together with steric effects, satisfactorily explain the trends in the k_o:k_p values.

The polar effect for a substituent will be identical from the para and ortho positions and will cancel in the ratio, k_o:k_p, if the susceptibility constants, ρ and ρ^*, are identical. The equivalence of ρ and ρ^* has been observed to be generally true.[6] Also, the equivalence of σ_p and σ^*, a property confirmed