therefore all kinetic measurements have been performed by discontinueous exposure of the sample to the light beam of the spectrophotometer.

Reactions with variable concentrations of PyCHO and metal perchlorate were performed under pseudo-first-order conditions, and k_{obsd} values were calculated according to the method of Guggenheim using the Beckman kinetic programme. The time taken between the runs was always longer than 2 half-lives. Good pseudo-first-order plots were obtained for reactions where sufficient metal ion was present in order to prevent loss of the phenanthroline-chelated metal ion to excess of PyCHO. For those reactions where PyCHO was in large excess over metal ion, however, the observed reaction rate rapidly decreases and initial reaction rates have been calculated.

Product Analysis. A solution of equivalent amounts (0.5 mmol) of 2-pyridinecarboxaldehyde, **3**, and zinc perchlorate in 25 mL of acetonitrile was kept under a nitrogen atmosphere in the dark for one night. The solvent was evaporated in vacuo, and 5 mL of an aqueous solution of 1 mmol of EDTA was added, followed by extraction of the mixture with 3 × 20 mL of dichloromethane. The organic layer was dried on Na_2SO_4, and after filtration the solution was evaporated, yielding 47 mg of a pale yellow oil. A sample of this residue was subjected to GC–MS analysis and identified as 2-pyridinemethanol (92%) and 2-pyridinecarboxaldehyde (8%). Column chromatography on silica ($CHCl_3$–CH_3OH, 95:5) yielded 37 mg (69%) of 2-pyridinemethanol. The ^1H NMR spectrum of this product was identical with that of an authentic sample.

Acknowledgment. We thank A. van Veldhuizen for his contribution to recording and analysis of NMR spectra and H. Jongejan for carrying out elemental analysis.

Notes

Ligand-Controlled α-Regioselectivity in Palladium-Catalyzed Arylation of Butyl Vinyl Ether

Walter Cabri,* Ilaria Candiani, and Angelo Bedeschi

Farmitalia Carlo-Erba S.r.l. (Erbamont Group), R&D, via Dei Gracchi 35, 20146 Milano, Italy

Roberto Santi

Istituto Guido Donegani, via Fauser 4, 28100 Novara, Italy

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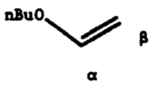
The palladium-catalyzed arylation of olefins (Heck reaction) is an extremely useful process for carbon–carbon bond formation;[1,2] unfortunately the use of acyclic enol ethers in this reaction is limited by poor α/β-regioselectivity (Figure 1). Preferential β-attack was observed with aromatic substrates bearing electron-withdrawing groups and when chloride or bromide anions are present in the oxidative addition intermediate.[3] On the other hand, high selectivity for the α position in acyclic systems has so far been observed only in a few cases[4a,b] and in reaction between vinyl triflates and enol ethers.[4c]

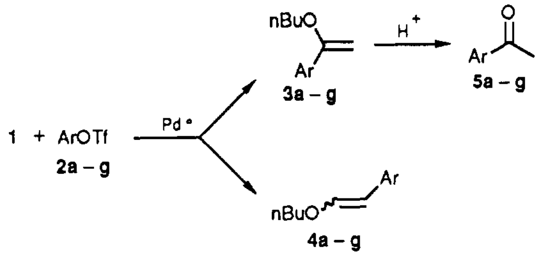
In connection with our previous work on the use of DPPP ligands in reactions of aryl triflates,[5] we investigated the Pd(AcO)$_2$-DPPP system in the reaction between aryl triflates and enol ethers.



1

Figure 1.

Scheme I[a]



[a] **a**, 1-naphthyl; **b**, *p*-NO$_2$-phenyl; **c**, *p*-CN-phenyl; **d**, *p*-CH$_3$CO-phenyl; **e**, phenyl; **f**, *p*-CH$_3$-phenyl; **g**, *p*-CH$_3$O-phenyl.

Table I. Palladium-Catalyzed Arylation of Butyl Vinyl Ether (1) with Naphthyl Triflate (2a)[a]

entry	solvent	ligand (L/Pd[b])	*T* (°C)	*t* (h)	**3a**/**4a**[c]	product (yield, %[d])
1	DMF	none	100	24[e]	54/46	**4a** (3)[f] + **5a** (4)
2	DMF	PPh$_3$ (2)	100	1.5	63/37	**4a** (32)[g] + **5a** (58)[h]
3	DMF	DPPP (1.1)	80	0.5	100/0	**5a**[h] (97)
4	DMF	DPPP (1.1)	60	1	100/0	**5a**[h] (91)
5	DMF	DPPP (1.1)	40	12.5	100/0	**5a**[h] (94)
6	dioxane	DPPP (1.1)	80	1.5	100/0	**5a**[h] (89)
7	toluene	DPPP (1.1)	80	2	100/0	**5a**[h] (95)

[a] The naphthyl triflate (3.6 mmol), butyl vinyl ether (18.1 mmol), triethylamine (7.24 mmol), Pd(OAc)$_2$ (0.09 mmol), and ligand were reacted in 10 mL of DMF. [b] Molar ratio between ligand and Pd(AcO)$_2$. [c] Determined by GLC of the crude products before acidic treatment. [d] Isolated yields. [e] Conversion (7%) and yields determined by GLC. [f] **4a** was present as a 71/29 *E*/*Z* mixture, determined by GLC. [g] **4a** was isolated as an 80/20 *E*/*Z* mixture, determined by GLC and ^1H NMR. [h] **5a**: bp 160–162 °C (11 mmHg), lit.[8] bp 167–170 °C (13 mmHg).

Results and Discussion

The catalyst generated in situ from 1,3-bis(diphenylphosphino)propane (DPPP) and Pd(AcO)$_2$ promotes the

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Table II. Palladium-Catalyzed α-Arylation of Butyl Vinyl Ether (1) with Triflates 2b–g[a]

entry	substr	T (°C)	t (h)	**3**/**4**[b]	product (yield, %[c])	mp (°C)[d]
1	**2b**	100	3.5	99/1[e]	**5b** (54)	79–81 (80–81)
2	**2c**	80	3	98/2[f]	**5c** (94)	59–61 (60–61)
3	**2d**	80	5	100/0	**5d** (96)	110–112 (114)
4	**2e**	100	2	100/0	**5e** (92)	78–80 (80–81)
5	**2f**	100	5	100/0	**5f** (89)	*g*
6	**2g**	100	5	100/0	**5g** (90)	37–39 (38–39)

[a] The triflate (0.6 mmol), butyl vinyl ether (3.0 mmol), triethylamine (1.2 mmol), DPPP (0.0165 mmol), and $Pd(OAc)_2$ (0.015 mmol) were reacted in 2 mL of DMF. [b] Determined by GLC of the crude products before acidic treatment. [c] Isolated yields. [d] In parentheses are mp from literature.[8] [e] Compound **4b** was isolated as an 80/20 E/Z mixture by flash chromatography[9] (J_{H-H} = 12.9 Hz, E isomer; J_{H-H} = 7.0 Hz, Z isomer). [f] Compound **4c** was isolated as a 16/84 E/Z mixture by flash chromatography[9] (J_{H-H} = 12.5 Hz, E isomer; J_{H-H} = 6.9 Hz, Z isomer). [g] **5f**: bp 119–121 °C (13 mmHg), lit.[8] bp 112.5 °C (11 mmHg).

reaction between butyl vinyl ether (**1**) and aryl triflates **2a–g**[6] with very high regioselectivity toward the α position. The well-known instability of the α-arylated products **3a–g**[7] allows one to obtain, after treatment with acids, the corresponding aryl methyl ketones **5a–g** (Scheme I). When **1** and naphthyl triflate (**2a**) were reacted in the absence of any palladium ligands, decomposition of the catalyst was observed; after 24 h only a small amount of the product was found in the reaction mixture (Table I, entry 1). This result is in agreement with the data reported by Hallberg on phenyl triflate.[3d]

In the presence of PPh_3 complete conversion with low selectivity toward α/β and E/Z isomers was observed (entry 2). The use of a DPPP-containing catalyst, very active in palladium-catalyzed reduction of aryl triflates,[5] allows one to obtain a complete selectivity toward the α-arylated product. The regioselectivity observed is independent both from reaction temperature (entries 3–5) and solvent (entries 6 and 7). These results prompted us to extend the reaction to substrates **2b–g**, containing substituents of different electronegativity, in order to check the scope and limitation of the method. The data obtained are reported in Table II. In every case almost complete α-regioselectivity and high yields (with exception of entry 1) were observed.

Electronic effects, exerted by the substrate, reported to play an important role in the regiochemistry in the absence of ligands,[3b] thus turn out to be not important in the presence of DPPP. On the other hand, with the exception of p-NO_2, electron-withdrawing groups at the para position increase the reaction rate, the reactivity order being p-CN > p-CH_3CO > H > p-CH_3 ≅ p-CH_3O. These results suggest that the slow step in this reaction is the oxidative addition of aryl triflates on the Pd^0 complex. The study of the factors favoring the formation of the α-arylated product in the presence of different ligands and leaving group are under investigation.

Summing up, we have developed a high yield method for the synthesis of aryl methyl ketones that offers a synthetical alternative to the Friedel–Crafts acylation and related reactions.

Experimental Section

All products were identified through their ^1H NMR spectra (Bruker AM 200; $CDCl_3$ as solvent with tetramethylsilane as an internal standard), mass spectra (CHS-DF Varian MAT-GC/MS), mp (determined on a Kofler apparatus and are uncorrected), or bp (bulb-to-bulb distillation conducted with a Büchi Kugelrohr apparatus) and by comparison with an authentic sample. The GLC analyses were carried out on a Carlo Erba HRGC 5300 chromatograph equipped with a Nordibond OV-1 column (25-m length, id 0.32 mm) and a flame ionization detector. Elemental analyses were performed by the microanalytical laboratory of the Istituto G. Donegani.

1,4-Dioxane and toluene were distilled from sodium and stored over activated 4A molecular sieves under argon. DMF and Et_3N were distilled from calcium hydride and stored over activated 4-Å molecular sieves under argon.

DPPP was an Aldrich product and used as received.

Palladium-Catalyzed Reaction. General Procedure (Table I, entry 3). To a stirred solution of **2a** (1 g, 3.62 mmol) in DMF (10 mL) under an argon atmosphere at room temperature were sequentially added Et_3N (0.731 g, 1 mL, 7.24 mmol), **1** (1.81 g, 2.3 mL, 18.1 mmol), DPPP (0.044 g, 0.1 mmol), and $Pd(AcO)_2$ (0.0203 g, 0.090 mmol). The reaction flask was heated to 80 °C. After 0.5 h the conversion was complete (GLC) and the reaction mixture was cooled to room temperature, 5% HCl (15 mL) was added, and after another 0.5 h of stirring the mixture was poured into CH_2Cl_2 (40 mL). The aqueous layer was extracted with CH_2Cl_2 (3 × 40 mL), and the combined organic layers were washed with water until neutrality, dried (anhydrous Na_2SO_4), filtered, and concentrated in vacuo. The crude product was purified by flash chromatography[9] (hexane/ethyl acetate 9/1 by volume), affording **5a** (0.604 g, 97%).

The only new product isolated was (Table I, entry 2) **(*E*/*Z*)-1-(2-butoxyethenyl)naphthalene (4a)** (32%): pale yellow oil; ^1H NMR δ 1.00 (t, J = 7.3 Hz, 3 H), 1.32–1.63 (m, 2 H), 1.64–1.86 (m, 2 H), 3.95 (t, J = 6.4 Hz, 2 H), 5.89 (d, J = 6.9 Hz, 0.2 H, Z isomer), 6.43 (d, J = 6.9 Hz, 0.2 H, Z isomer), 6.5 (d, J = 12.5 Hz, 0.8 H, E isomer), 6.95 (d, J = 12.5 Hz, 0.8 H, E isomer), 7.20–8.22 (m, 7 H); GLC-MS (E)-**4a** m/e 226 (M^+), 170 (100), 169, 141, (Z)-**4a** m/e 226 (M^+), 170 (100), 169, 141.

Anal. Calcd for $C_{16}H_{18}O$: C, 84.91, H, 8.02. Found: C, 84.89; H, 8.04.

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Rotation Barrier in a Doubly Vinylogous Amide

Hugo E. Gottlieb,* Samuel Braverman, and Shlomo Levinger

Department of Chemistry, Bar-Ilan University,
Ramat-Gan 52100, Israel

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In the course of a synthesis of nicotinaldehyde, we followed the method of Arnold.[1] This involves a bis-Vilsmeier–Haack formylation of aminoenamine **1**, which is readily obtained from crotonaldehyde. The product of this reaction, an orange crystalline material with a violet luster and a sharp melting point, was described by Arnold as having structure **2**, but alternative **3** was not excluded.[1] On the basis of NMR spectroscopy, we can establish **3** as the correct structure for this substance, but in addition, we notice broad lines characteristic of an ongoing dynamic process. In this paper we determine the nature and the energy barrier of this process.

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