The Palladium-Catalyzed Arylation of Enol Esters, Ethers, and Halides. A New Synthesis of 2-Aryl Aldehydes and Ketones

R. F. Heck

*Contribution from the Research Center of Hercules Inc.,
Wilmington, Delaware 19899.* *Received December 7, 1967*

Abstract: Arylpalladium salts, generated *in situ* from arylmercury salts and palladium salts, react with aldehyde enol esters to form arylacetaldehyde derivatives, arylacetaldehyde enol ester derivatives, arylethylenes, and stilbenes. Vinyl ethers and halides react also, forming stilbenes. Ketone enol esters and arylpalladium salts form α-aryl ketones as the major products. Yields have been generally low but, nonetheless, the reactions provide very simple and convenient methods for obtaining numerous substituted 2-arylaldehydes and ketones.

The arylation of unsaturated compounds with group VIII metal aryls has proved to be a very general reaction. Several new useful synthetic organic reactions are based upon this arylation: olefin arylation,[1] aromatic haloethylation,[2] aromatic allylation,[3] and a 3-aryl aldehyde or ketone synthesis by the arylation of allylic alcohols.[4] In this paper is reported still another useful arylation reaction—the arylation of enol esters, ethers, and halides.

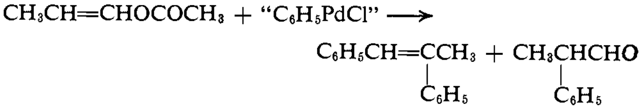
Results and Discussion

Arylpalladium salts, prepared *in situ* by the exchange reaction of palladium salts with arylmercuric salts, were allowed to react with various enol esters, ethers, and halides. Enol esters of aldehydes produced mixtures of arylacetaldehyde enol esters, arylacetaldehydes, arylethylenes, and stilbene derivatives. Enol ethers and halides gave mainly stilbenes. Enol esters of ketones produced only α-arylated ketones in the reaction. As with the other olefin arylations, the reaction goes best in polar solvents such as acetonitrile, acetone, and acetic acid, which dissolve the salts. Increasing substitution at the double bond decreased the yield of arylation product in the enol ester arylation as it does in other olefin arylations,[1] but even isobutyraldehyde enol acetate reacted to give a low yield of product. The reactions carried out are listed in Table I. The reactions were generally made catalytic in palladium by adding cupric chloride to reoxidize the product palladium to the reactive Pd(II) form.

Vinyl acetate, propenyl acetate, and isopropenyl acetate were the most thoroughly studied. In acetic acid, vinyl acetate reacted with "phenylpalladium chloride" to produce nearly equal amounts of *trans*-stilbene, phenylacetaldehyde, and phenylacetaldehyde enol acetate, along with a few per cent of styrene.

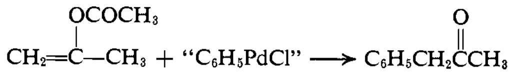
$$CH_2{=}CHOCOCH_3 + \text{“}C_6H_5PdCl\text{”} \longrightarrow C_6H_5CH{=}CHC_6H_5 + C_6H_5CH_2CHO + C_6H_5CH{=}CHOCOCH_3 + C_6H_5CH{=}CH_2$$

Under similar conditions, propenyl acetate (*cis* and *trans* mixture) produced about three times as much 1,2-diphenyl-1-propene as 2-phenylpropionaldehyde.



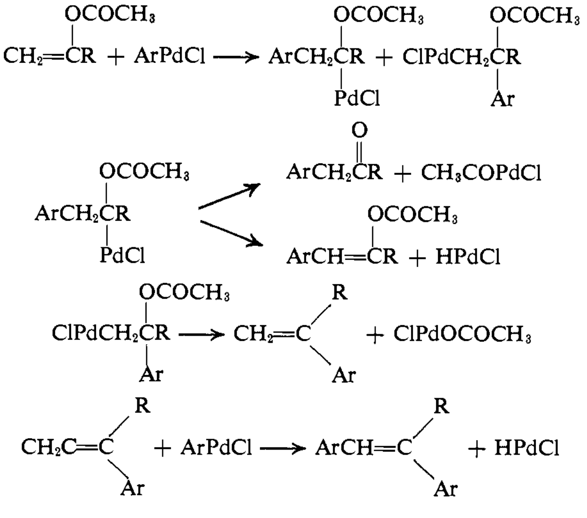
$$CH_3CH{=}CHOCOCH_3 + \text{“}C_6H_5PdCl\text{”} \longrightarrow C_6H_5CH{=}\underset{\substack{|\\ C_6H_5}}{C}CH_3 + CH_3\underset{\substack{|\\ C_6H_5}}{C}HCHO$$

Analyses were not made for the enol acetate in this example. Isopropenyl acetate and "phenylpalladium chloride," under similar conditions, yielded phenylacetone as the only major product.



$$CH_2{=}\overset{\substack{OCOCH_3\\ |}}{C}{-}CH_3 + \text{“}C_6H_5PdCl\text{”} \longrightarrow C_6H_5CH_2\overset{\substack{O\\ \|}}{C}CH_3$$

The data suggest that the mechanism of the enol ester arylation involves an addition elimination sequence. Addition to the enol ester clearly can occur in either direction. The electronically preferred direction of addition appears to be to add the aryl group to the carbon attached to the ester group while sterically the aryl group tends to attach itself to the least substituted carbon atom of the double bond. After addition occurs, elimination of the palladium group can take place in two different ways. If the palladium is attached to the double bond carbon not bonded to the ester group, elimination of the benzylic acetate group must occur with the palladium producing the arylethylene product. Since the arylethylene is generally more reactive than the enol ester toward the arylating agent, most of the arylethylene is arylated again to produce a stilbene derivative. In the initially formed adduct where palladium is attached to the carbon bearing the ester group, elimination of palladium with a neighboring hydride produces arylated enol ester,



$$CH_2{=}\overset{\substack{OCOCH_3\\ |}}{C}R + ArPdCl \longrightarrow ArCH_2\overset{\substack{OCOCH_3\\ |}}{\underset{\substack{|\\ PdCl}}{C}}R + ClPdCH_2\overset{\substack{OCOCH_3\\ |}}{\underset{\substack{|\\ Ar}}{C}}R$$

$$ArCH_2\overset{\substack{OCOCH_3\\ |}}{\underset{\substack{|\\ PdCl}}{C}}R \begin{array}{l} \nearrow ArCH_2\overset{\substack{O\\ \|}}{C}R + CH_3COPdCl \\ \searrow ArCH{=}\overset{\substack{OCOCH_3\\ |}}{C}R + HPdCl \end{array}$$

$$ClPdCH_2\overset{\substack{OCOCH_3\\ |}}{\underset{\substack{|\\ Ar}}{C}}R \longrightarrow CH_2{=}C\begin{matrix} R\\ Ar \end{matrix} + ClPdOCOCH_3$$

$$CH_2C{=}C\begin{matrix} R\\ Ar \end{matrix} + ArPdCl \longrightarrow ArCH{=}C\begin{matrix} R\\ Ar \end{matrix} + HPdCl$$

---

[1] R. F. Heck, *J. Amer. Chem. Soc.*, **90**, 5518 (1968).

[2] R. F. Heck, *ibid.*, **90**, 5538 (1968).

[3] R. F. Heck, *ibid.*, **90**, 5531 (1968).

[4] R. F. Heck, *ibid.*, **90**, 5526 (1968).

Table I. Arylation Reactions of Enol Esters, Ethers, and Halides

Reactants						Yield, %
Mercurial	Enol compd	Catalyst	Reoxidant	Solvent	Products	
C_6H_5HgCl	$CH_2=CHOAc$	Li_2PdCl_4	$CuCl_2$	HOAc	*trans*-$C_6H_5CH=CHC_6H_5$	34
					$C_6H_5CH_2CHO$	33
					$C_6H_5CH=CHOAc$	30
					$C_6H_5CH=CH_2$	3
C_6H_5HgCl	$CH_2=CHCl$	Li_2PdCl_4	$CuCl_2$	HOAc	*trans*-$C_6H_5CH=CHC_6H_5$	35
C_6H_5HgOAc	$CH_2=CHOAc$	$Pd(OAc)_2$	$Hg(OAc)_2$	HOAc	*trans*-$C_6H_5CH=CHC_6H_5$	13
					$C_6H_5CH_2CHO$	Trace
C_6H_5HgCl	$CH_2=CHOAc$	$LiPdCl_3$	$CuCl_2$	CH_3CN	*trans*-$C_6H_5CH=CHC_6H_5$	20
					$C_6H_5CH_2CHO$	8
					$C_6H_5CH=CH_2$	2
C_6H_5HgCl	$CH_2=CHOAc$	Li_2PdCl_4	$CuCl_2$	CH_3COCH_3	*trans*-$C_6H_5CH=CHC_6H_5$	31
					$C_6H_5CH_2CHO$	10
					$C_6H_5CH=CH_2$	3
C_6H_5HgCl	$CH_2=CHOC_4H_9$	$LiPdCl_3$	$CuCl_2$	CH_3CN	*trans*-$C_6H_5CH=CHC_6H_5$	11
					$C_6H_5CH_2CHO$	Trace
					$(C_6H_5)_2$	48
					C_6H_5Cl	31
C_6H_5HgCl	$CH_2=CHOCOCF_3$	$LiPdCl_3$	$CuCl_2$	CH_3CN^a	*trans*-$C_6H_5CH=CHC_6H_5$	26
					Styrene	Trace
$3\text{-}NO_2C_6H_4HgCl$	$CH_2=CHOAc^b$	Li_2PdCl_4	$CuCl_2$	CH_3COCH_3	$(3\text{-}NO_2C_6H_4)CH=CH(3\text{-}NO_2C_6H_4)$	9
$3\text{-}CH_3OCOC_6H_4\text{-}HgCl$	$CH_2=CHOAc$	$LiPdCl_3$	$CuCl_2$	CH_3CN	$(3\text{-}CH_3OCOC_6H_4)CH=CH(3\text{-}CH_3OCOC_6H_4)$	9
C_6H_5HgCl	$CH_3CH=CHOAc^b$	Li_2PdCl_4	$CuCl_2$	HOAc	$CH_3CH(C_6H_5)CHO$	21
					$C_6H_5CH=C(C_6H_5)CH_3$	66
C_6H_5HgCl	$CH_3CH=CHOAc^b$	Li_2PdCl_4	$CuCl_2$	CH_3COCH_3	$CH_3CH(C_6H_5)CHO$	29
					$C_6H_5CH=C(C_6H_5)CH_3$	18
C_6H_5HgCl	$CH_3CH=CHOAc^b$	$LiPdCl_3$	$CuCl_2$	CH_3CN	$CH_3CH(C_6H_5)CHO$	11
					$C_6H_5CH=C(C_6H_5)CH_3$	39
C_6H_5HgCl	$CH_3CH=CHBr^b$	$LiPdCl_3$	$CuCl_2$	CH_3CN	$C_6H_5CH=C(C_6H_5)CH_3$	14
					C_6H_5Cl	46
$4\text{-}CH_3OC_6H_4HgCl$	$CH_3CH=CHOAc^b$	Li_2PdCl_4	$CuCl_2$	HOAc	$CH_3CH(4\text{-}CH_3OC_6H_4)CHO$	18
					$(4\text{-}CH_3OC_6H_4)CH=C(4\text{-}CH_3OC_6H_4)\text{-}CH_3$	3
$3\text{-}NO_2C_6H_4HgCl$	$CH_3CH=CHOAc^b$	Li_2PdCl_4	$CuCl_2$	HOAc	$(3\text{-}NO_2C_6H_4)CH=C(3\text{-}NO_2C_6H_4)CH_3$	1
C_6H_5HgCl	$(CH_3)_2C=CHOAc$	$Li_2PdCl_4^c$	$CuCl_2$	7:1 $HOAc\text{-}H_2O$	$(CH_3)_2C(C_6H_5)CHO$	7
C_6H_5HgCl	$CH_3CH(OAc)=CH_2$	$Li_2PdCl_4^c$	$CuCl_2$	7:1 $HOAc\text{-}H_2O$	$C_6H_5CH_2COCH_3$	50
					C_6H_5Cl	40
$4\text{-}HOCOC_6H_4HgCl$	$CH_3CH(OAc)=CH_2$	Li_2PdCl_4	$CuCl_2$	19:1 $HOAc\text{-}H_2O$	$4\text{-}HOCOC_6H_4CH_2COCH_3$	4
C_6H_5HgCl	$C_6H_5C(OCOC_6H_5)=CH_2$	Li_2PdCl_4	$CuCl_2$	CH_3COCH_3	$C_6H_5CH_2COC_6H_5$	40
$3\text{-}NO_2C_6H_4HgCl$	$C_6H_5C(OAc)=CH_2$	Li_2PdCl_4	. . .	19:1 $CH_3OH\text{-}H_2O$	$3\text{-}NO_2C_6H_4CH_2COC_6H_5$	9
$3,4\text{-}Cl_2C_6H_3HgCl$	$4\text{-}CH_3OC_6H_4C(OAc)=CH_2$	Li_2PdCl_4	. . .	25:1 $CH_3OH\text{-}H_2O$	$3,4\text{-}Cl_2C_6H_3CH_2CO(4\text{-}CH_3OC_6H_4)$	8

[a] Dicyclohexylethylamine also added to neutralize $HOCOCF_3$ as it was formed. [b] Mixture of *cis* and *trans* isomers. [c] Lithium chloride also added.

while elimination with an acyl group produces a carbonyl compound. It is clear that the carbonyl compound is not all coming from hydrolysis of the arylated enol ester since carbonyl compounds are formed even in anhydrous acetonitrile solution.

The usefulness of the aldehyde enol ester arylation reaction is limited because mixtures of products are often obtained, but the reaction does offer a very convenient method for producing α-aryl aldehydes. The formation of stilbene derivatives by this reaction is of less interest because they can be better synthesized by the direct arylation of styrenes.[1] The preparation of α-aryl ketones from ketone enol esters is also a very convenient reaction although yields have been low. Further improvements very probably can be made to increase the usefulness of the reactions.

Experimental Section

Reagents. The mercurials, solvents, and palladium salts employed in this work were prepared as described previously.[1]

Phenylation of Vinyl Acetate. A mixture of 10 mmol of phenylmercuric chloride, 10 mmol of cupric chloride, 8 ml of acetic acid, 2 ml of vinyl acetate, and 1 ml of 0.1 *M* Li_2PdCl_4 in acetic acid was stirred at room temperature overnight. Analyses by gas chromatography then showed the solution to be 0.15 *M* in *trans*-stilbene, 0.30 *M* in phenylacetaldehyde, 0.27 *M* in phenylacetaldehyde enol acetate, and 0.03 *M* in styrene. Other reactions listed in Table I were carried out similarly.

A reaction mixture containing 10 mmol of $HgCl_2$, 10 mmol of cupric chloride, 8 ml of acetic acid, 2 ml of vinyl acetate, 1 ml of 0.1 *M* Li_2PdCl_4 in acetic acid, and 1 ml of phenylacetaldehyde failed to form any phenylacetaldehyde enol acetate on reacting overnight.

Another reaction mixture containing 5 mmol of phenylmercuric chloride, 5 mmol of cupric chloride, 5 ml of 0.1 *M* phenylacetaldehyde enol acetate in acetic acid, 5 ml of acetic acid, and 1 ml of 0.1 *M* Li_2PdCl_4 in acetic acid produced no stilbene or styrene and very little phenylacetaldehyde after reacting overnight.

Phenylacetaldehyde. A mixture of 50 mmol of phenylmercuric chloride, 50 mmol of lithium chloride, 50 mmol of cupric chloride, 37 ml of acetic acid, 2.5 ml of water, 5 ml of vinyl acetate, and 5 ml of 0.1 *M* Li_2PdCl_4 in acetic acid was stirred at room temperature for 2 hr. Three such reaction mixtures were then combined, diluted with water, and extracted with four portions of methylene chloride. The combined extracts were washed with water, dried over anhydrous magnesium sulfate, and distilled under reduced pressure. There was obtained 5.2 g of colorless product, bp 71–80° (7 mm), which was about 85% phenylacetaldehyde by gas chromatographic analysis. The product gave a yellow 2,4-dinitrophenylhydrazone derivative, mp 116–116.5° after recrystallization from ethanol.

Anal. Calcd for $C_{14}H_{12}N_4O_4$: C, 56.00; H, 4.03; N, 18.66. Found: C, 56.25; H, 4.20; N, 18.72.

Table II. Analyses and Spectral Properties of Enol Ester Arylation Products

Compound	Bp (mm) or mp (lit.), °C	Found, %			Calcd, %			Spectra: uv,[a] mμ (ε); ir,[b] cm^{-1}; nmr, ppm (no. of protons)
		C	H	Other	C	H	Other	
3,3′-Dinitrostilbene	245–245.5	62.26	3.91	10.46 (N)	62.22	3.73	10.37 (N)	Uv 283 (34,000)
3,3′-Bis(carbomethoxy)stilbene	152.0–152.5	72.41	5.69	. . .	72.96	5.44	. . .	Ir 1725
2-Phenylpropionaldehyde	60–70 (4 mm)	79.47	7.78	. . .	80.56	7.51	. . .	Nmr −9.52, doublet (1) −7.15, multiplet (5) −3.48, 8 lines (1) −1.35, doublet (3)
1,2-Diphenyl-1-propene	88.5–89.0	92.42	7.42	. . .	92.74	7.26	. . .	Nmr −7.24, multiplets (10) −6.73, doublet (1) −2.22, 2 lines (3)
2-*p*-Anisylpropionaldehyde	100–120 (2 mm)	72.84	7.71	. . .	73.14	7.37	. . .	Nmr −9.60, singlet (1) −6.90, multiplet (4) −3.64, singlet (3), −2.70, multiplet (4)
1,2-Di-*p*-anisyl-1-propene	123.5–124.5	80.69	7.28	. . .	80.28	7.13	. . .	Uv 287 (28,000)
1,2-Bis(3-nitrophenyl-1-propene	201–202	60.91	4.15	9.30 (N)	63.37	4.26	9.86 (6)	
2-Methyl-2-phenylpropionaldehyde	77–110 (4 mm)	79.65	8.76	. . .	81.04	8.16	. . .	Nmr −9.30, singlet (1) −7.13, multiplet (5) −1.35, singlet (6)
4-Carboxybenzyl methyl ketone	143–144	67.25	5.94	. . .	67.40	5.66	. . .	
Benzyl phenyl ketone	55–56 (55–56)[c]	85.82	6.49	. . .	85.68	6.17	. . .	Ir 1640, 1720
3-Nitrobenzyl phenyl ketone	79.5–80.5	69.64	5.02	5.60 (N)	69.70	4.60	5.81 (N)	Uv 247 (18,000)
p-Anisyl 3,4-dichlorobenzyl ketone	113.0–113.5	60.88	4.59	. . .	61.03	4.10	. . .	

[a] In isooctane solution. [b] In $CHCl_3$ solution. [c] A. H. Blatt, "Organic Syntheses," Coll. Vol. II, John Wiley and Sons, Inc., New York, N. Y., 1943, p 156.

3,3′-Dinitrostilbene. A mixture of 10 mmol of 3-nitrophenylmercuric chloride, 10 mmol of lithium chloride, 10 mmol of cupric chloride, 1 ml of vinyl acetate, 9 ml of acetone, and 1 ml of 0.1 *M* Li_2PdCl_4 in acetone was stirred at room temperature overnight. The reaction mixture was then diluted with methylene chloride and poured into an alumina column. The yellow product was eluted with more methylene chloride. Evaporation of the eluate and two recrystallizations from acetic acid gave 0.112 g of yellow crystals, mp 245.0–245.5°. In isooctane solution, the compound had λ_{max} 283–288 mμ (ε 35,800). Analysis and spectral data are given in Table II.

3,3′-Bis(carbomethoxy)stilbene. A mixture of 10 mmol of methyl 3-chloromercuribenzoate, 10 mmol of cupric chloride, 2 ml of vinyl acetate, and 10 ml of 0.1 *M* $LiPdCl_3$ in acetonitrile was stirred at room temperature overnight. The product was isolated as in the 3,3′-dinitrostilbene preparation above. Two recrystallizations of the crude product from methanol gave 0.137 g of colorless crystals, mp 152–152.5°. In isooctane solution the compound had bands at 317 mμ (shoulder) (ε 16,000), 290 (27,800), 238 (26,800), and 230 (25,200). Analysis and other spectral bands are given in Table II.

Phenylation of Propenyl Acetate. A mixture of 10 mmol of phenylmercuric chloride, 10 mmol of cupric chloride, 9 ml of acetic acid, 1 ml of propenyl acetate, and 1 ml of Li_2PdCl_4 in acetic acid was stirred at room temperature overnight. Analysis of the reaction mixture by gas chromatography showed that the concentration of 2-phenylpropionaldehyde was 0.19 *M* and 1,2-diphenyl-1-propene was 0.30 *M* (*trans* isomer).

2-Phenylpropionaldehyde and 1,2-Diphenyl-1-propene. A mixture of 50 mmol of phenylmercuric chloride, 50 mmol of cupric chloride, 50 mmol of lithium chloride, 5 ml of propenyl acetate, 35 ml of acetic acid, 5 ml of water, and 5 ml of 0.1 *M* Li_2PdCl_4 in acetic acid was stirred at room temperature overnight. Four similar reaction mixtures were then combined, diluted with water, and extracted with methylene chloride several times. After being washed with water and dried over anhydrous magnesium sulfate, the extracts were distilled under reduced pressure. There was obtained 5.4 g of colorless liquid, bp 60–70° (4 mm), which was about 95% 2-phenylpropionaldehyde by gas chromatographic analysis. The nmr spectrum of this material is given in Table II. A second fraction from the distillation of the extracts, bp 120–160° (4 mm), solidified on cooling. Several recrystallizations from aqueous methanol gave 0.63 g of colorless plates, mp 88.5–89.0°, which were *trans*-1,2-diphenyl-1-propene. In isooctane solution, the compound had λ_{max} 272 mμ (ε 20,000). Analysis and nmr data are given in Table II.

2-*p*-Anisylpropionaldehyde and 1,2-Di-*p*-anisyl-1-propene. A mixture of 0.10 mol of *p*-anisylmercuric chloride, 0.10 mol of cupric chloride, 80 ml of acetic acid, 0.10 mol of lithium chloride, 20 ml of propenyl acetate, and 10 ml of 0.1 *M* Li_2PdCl_4 in acetic acid was stirred at room temperature for 3 hr. The reaction mixture was then poured into water and the products were extracted from the mixture with pentane. After being washed with water and aqueous sodium bicarbonate, the extracts were dried over anhydrous magnesium sulfate and distilled under reduced pressure. The fraction with bp 100–120° (2 mm), weighing 3.75 g, was about 80% 2-*p*-anisylpropionaldehyde by gas chromatographic analysis. A sample was obtained by preparative scale gas chromatography for analysis and an nmr spectrum determination. The pot residue from the distillation was recrystallized from hexane and from aqueous ethanol to give 0.435 g of colorless plates, mp 123.5–124.5°, which proved to be 1,2-di-*p*-anisyl-1-propene. In isooctane solution, the compound showed λ_{max} 287 mμ (ε 28,000). Analyses and nmr data are given in Table II.

1,2-Bis(3-nitrophenyl)-1-propene. A reaction mixture containing 0.10 mol of 3-nitrophenylmercuric chloride, 0.10 mol of cupric chloride, 90 ml of acetic acid, 10 ml of propenyl acetate, and 10 ml of 0.1 *M* Li_2PdCl_4 in acetic acid was stirred at room temperature overnight. The reaction mixture was diluted with water and the products were extracted with ether. After being washed with water and aqueous bicarbonate, the extracts were dried over anhydrous magnesium sulfate, concentrated on the steam bath to a yellow oil, and chromatographed on alumina. Methylene chloride eluted a yellow product which, after recrystallization from alcohol, had the mp 200–201° and weighed 0.23 g. Another recrystallization from alcohol gave 0.13 g of pale yellow crystals of mp 201.5–202.0°.

2-Methyl-2-phenylpropionaldehyde. A reaction was carried out as in the 2-phenylpropionaldehyde preparation above, with isobutyraldehyde enol acetate in place of propenyl acetate. There was obtained 3 g of liquid product with bp 77–100° (4 mm) which was about 50% 2-methyl-2-phenylpropionaldehyde by gas chromatographic analysis. A pure sample was isolated by preparative-scale gas chromatography. Analysis and nmr data are given in Table II.

Benzyl Methyl Ketone. A reaction mixture containing 10 mmol of phenylmercuric chloride, 10 mmol of lithium chloride, 10 mmol of cupric chloride, 7 ml of acetic acid, 1 ml of water, 1 ml of isopropenyl acetate, and 1 ml of 0.1 *M* Li_2PdCl_4 in acetic acid was stirred at room temperature overnight. Gas chromatographic analysis then showed that the reaction mixture was 0.50 *M* in benzyl methyl ketone and about 0.4 *M* in chlorobenzene.

4-Carboxybenzyl Methyl Ketone. A reaction mixture containing 10 mmol of 4-chloromercuribenzoic acid, 2 ml of isopropenyl acetate, 5 ml of water, and 100 ml of 0.1 M Li_2PdCl_4 in acetic acid was stirred at room temperature for 3 days. The reaction mixture was then filtered to remove precipitated palladium metal and evaporated under reduced pressure. The residue remaining was extracted with hot hexane. On cooling, the hexane solution deposited crystals of the product. Two further recrystallizations from hexane gave 62 mg of colorless needles, mp 143–144°.

Benzyl Phenyl Ketone. A reaction mixture containing 0.10 mol of phenylmercuric chloride, 0.10 mol of cupric chloride, 20 ml of acetophenone enol benzoate[5] and 100 ml of 0.1 M Li_2PdCl_4 in acetone was stirred at room temperature for 3 hr. Gas chromatographic analysis then showed that the solution was 0.33 M in benzyl phenyl ketone. Isolation of the product by adding water and extracting with pentane as in the 2-*p*-anisylpropionaldehyde preparation above gave 10.8 g of product, bp 105–165° (4 mm), which was a mixture of the desired ketone and unreacted acetophenone enol benzoate. Two recrystallizations from pentane gave 5.4 g of colorless crystals, mp 50.5–52.5°. The melting point rose to 55–56° after several more recrystallizations from hexane.

3-Nitrobenzyl Phenyl Ketone. A mixture of 8.8 mmol of 3-nitrophenylmercuric chloride, 1.1 ml of acetophenone enol acetate,[6] 5 ml of water, and 100 ml of 0.1 M Li_2PdCl_4 in methanol was stirred at room temperature overnight. The reaction mixture was then filtered and the solvent was removed under reduced pressure. The product was extracted from the residue with hot hexane. On cooling, sticky crystals separated from the hexane solution. Two recrystallizations from aqueous methanol gave 0.20 g of colorless needles, mp 79.5–80.5°.

***p*-Anisyl 3,4-Dichlorobenzyl Ketone.** A reaction mixture containing 1.5 g (4 mmol) of 4-chloromercuric-1,2-dichlorobenzene, 0.54 g of *p*-methoxyacetophenone enol acetate (mp 68–70°),[6] 2 ml of water, and 5 ml of 0.1 M Li_2PdCl_4 in methanol was stirred at room temperature overnight. Isolation of the product as in the 3-nitrobenzyl phenyl ketone preparation above and three recrystallizations from aqueous methanol gave 92 mg of colorless needles of product, mp 113.0–113.5°.

Acknowledgment. The author gratefully acknowledges the assistance of Mr. Joseph Keelins with the experimental work. The nmr spectra were measured by Dr. George Ward.

---

[5] F. Lees, *J. Chem. Soc.*, **83**, 145 (1903).

[6] Prepared by the procedure of P. A. Bedoukian, *J. Amer. Chem. Soc.*, **67**, 1430 (1945).

Aromatic Haloethylation with Palladium and Copper Halides

R. F. Heck

Contribution from the Research Center of Hercules Inc.,
Wilmington, Delaware 19899. *Received December 7, 1967*

Abstract: Aryl derivatives of group VIII metal compounds, prepared from group VIII metal salts and mercury, tin, or lead aryls, react with olefins in the presence of cupric halides to form 2-arylethyl halides. Chlorides are formed in higher yields than bromides. The most generally useful and readily obtainable reactants were arylmercuric halides, with lithium palladium chloride as the group VIII metal compound. Since only catalytic amounts of the palladium salt are required, this reaction provides a convenient method for introducing 2-haloethyl groups into aromatic systems.

Aryl derivatives of the group VIII metals react with olefins to form arylated olefins, an acid, and a reduced metal salt or the metal itself.[1] For example, "phenylpalladium chloride," prepared from phenylmercuric chloride and lithium palladium chloride *in situ*, reacts with ethylene to form styrene, hydrogen chloride, and palladium metal. The reaction can be

$$C_6H_5HgCl + PdCl_2 \rightleftharpoons [C_6H_5PdCl] + HgCl_2$$

$$[C_6H_5PdCl] + CH_2{=}CH_2 \longrightarrow C_6H_5CH{=}CH_2 + HCl + Pd$$

made catalytic with respect to palladium if certain oxidizing agents are included in the reaction mixture to reoxidize elemental palladium. Cupric chloride was a very effective reoxidant in this reaction at relatively low (<0.5 M) concentrations. At higher concentrations, reoxidation of the palladium still occurred, but a side reaction became important. As the concentration of cupric chloride was increased, increasing amounts of arylethyl chlorides were formed at the expense of the arylated olefin. A study of this aromatic haloethylation reaction is the subject of this paper.

Results

A study of the variables in the reaction of phenylmercuric chloride, cupric chloride, and ethylene with a lithium palladium chloride catalyst revealed that 2-phenethyl chloride could be produced in 76% yield under practical conditions. Acetic acid or aqueous acetic acid is the best solvent, and the concentration of cupric chloride should be about 2 M. The inclusion of lithium chloride in the reaction mixture had a beneficial effect, presumably because it solubilized the cupric chloride. The reaction was found to be quite general. Arylethyl bromides were obtained by the same procedure with cupric bromide but in lower yields. Aryltin and -lead compounds could also be used as well as mercurials as the arylating agents, and salts of group VIII metals other than palladium, particularly rhodium and ruthenium, were also catalysts for the reaction. Some of the reactions carried out are summarized in Table I.

By-products in the haloethylation reaction include arylated olefins, aryl halides, α-haloarylethanes, and biaryls. In alcoholic solvents, the halides were sometimes converted into ethers under the reaction conditions if the halides were unusually reactive. Olefins

---

[1] R. F. Heck, *J. Amer. Chem. Soc.*, **90**, 5518 (1968).