

Studies on Benzofurylmercuric Compound

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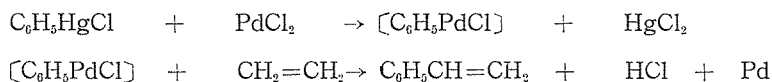
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Abstract

In the presence of sodium acetate, benzofuran and mercuric chloride in aqueous ethyl alcohol give 2-benzofurylmercuric chloride (2). 2 is also prepared from coumarilic acid and mercuric chloride. 2 is converted by sodium thiosulfate into di-2-benzofurylmercury, and the reaction of 2 with acetyl chloride gives 2-benzofuryl methyl ketone identical with a specimen prepared from benzofuran, acetyl chloride, and stannic chloride. In the presence of lithium chloropalladite, the reactions of 2 with various olefins afford 2-benzofuryl-substituted olefins, accompanied by a small amount of 2,2'-bibenzofuryl. Furthermore, in the presence of palladium salts, 2 is carbonylated in methanol to afford methyl coumarilate, di-2-benzofuryl ketone, and 2,2'-bibenzofuryl.

Introduction

The reactions of olefins in the presence of transition metal compounds have been studied by many workers.²⁾ Recently, the arylation of olefins with arylpalladium compound, formed *in situ* by the exchange of arylmercuric compounds with Group VIII metal salts, has been shown to be a useful reaction for the synthesis of various olefinic compounds³⁾. For example, "phenylpalladium chloride", prepared from phenylmercuric chloride and a palladium salt *in situ*, reacts with ethylene to form styrene, hydrogen chloride, and palladium metal.



Furthermore, we described the ferrocenylation of olefins with chloromercuriferrocene in the presence of palladium salt to produce alkenylferrocene derivatives.⁴⁾ In order to study whether or not the Heck reaction occurs with nonbenzenoid aromatic mercuric compounds, the reaction of olefins with 2-benzofurylmercuric chloride (2) was performed in the presence of palladium salt.

Results and Discussion

Preparation of Mercurial (2). It has been reported that furan reacts at room temperature with a buffered solution of mercuric chloride to give a mixture of 2-chloromercurifuran and 2,5-dichloromercurifuran.⁵⁾ 2-Chloromercurifuran also prepared from the reaction of sodium 2-furoate and mercuric chloride,⁵⁾ and Büchi and coworkers⁶⁾ reported that the reaction of lithium 3-methyl-2-furoate with mercuric chloride affords to 3-methyl-2-furylmercuric compound. In the mercuriation of benzofuran (1), in an aqueous ethanol solution 1 reacted with one equivalent of mercuric chloride and four of sodium acetate to give 2 in a 50% yield. On the other hand, the reaction of sodium coumarilate with mercuric chloride also afforded 2 in a 64% yield.

The treatment of 2 with acetyl chloride gave 2-benzofuryl methyl ketone(3), which is identical with a specimen prepared from 1, acetyl chloride, and stannic chloride. The mercuric chloride group, therefore, entered the 2-position in 1, on the assumption that its replacement by acetyl proceeds normally. Similarly, the reaction of 2 with benzoyl chloride afforded 2-benzofuryl phenyl ketone (4). The reduction of 2 with sodium thiosulfate converted to di-2-benzofurylmercury (5), whereas 2 reacted smoothly with bromine to afford 2-bromobenzofuran (6).

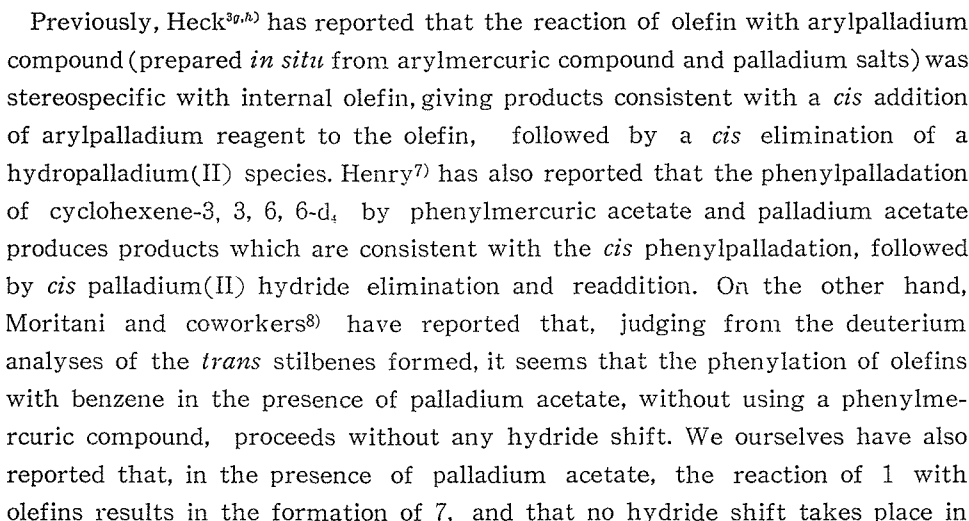
Reaction of 2 with olefins. In the presence of lithium chloropalladite, 2 was allowed to react with various olefins in polar solvents, such as methanol

Table I. The reactions of 2- benzofurylmercuric chloride (2) with olefin.

Olefin	solvent	Product	Yield% ^{a)}
Styrene	CH ₃ OH	2-Styrylbenzofuran (7-a) ^{b)}	48
		2, 2'-Bibenzofuryl (8) ^{c)}	8
Styrene	C ₂ H ₅ OH	2-Styrylbenzofuran (7-a) ^{b)}	45
		2, 2'-Bibenzofuryl (8) ^{c)}	8
Styrene	CH ₃ CN	2-Styrylbenzofuran (7-a) ^{b)}	51
		2, 2'-Bibenzofuryl (8) ^{c)}	8
Ethyl acrylate	C ₂ H ₅ OH	Ethyl 2-(2-benzofuryl)-acrylate (7-b) ^{d)}	43
		2, 2'-Bibenzofuryl (8) ^{c)}	9
Methyl methacrylate	CH ₃ OH	Methyl 2-(2-benzofuryl)-methacrylate (7-c) ^{e)}	43
		2, 2'-Bibenzofuryl(8) ^{c)}	10
		Ethyl 2-(2-benzofuryl)-crotonate(7-d) ^{f)}	45
Acrylonitrile	CH ₃ CN	2, 2'-Bibenzofuryl(8) ^{c)}	7
		2-(2-Benzofuryl)-acrylonitrile (7-e) ^{g)}	48
		2, 2'-Bibenzofuryl (8) ^{c)}	8

a) Yields are based upon the used mercurial (2).

b) Mp 121—122°C, (lit.^{h)} mp 121—122°C).

$$\begin{array}{l} \text{RHgCl} \quad + \quad \text{Li}_2\text{PdCl}_4 \longrightarrow [\text{RPdCl}] \quad + \quad \text{HgCl}_2 \quad + \quad 2\text{LiCl} \\ (2) \qquad \qquad \qquad (9) \\ 2[\text{RPdCl}] \qquad \qquad \qquad \longrightarrow \text{R-R} \quad + \quad \text{PdCl}_2 \quad + \quad \text{Pd} \\ \qquad \qquad \qquad \qquad \qquad \qquad (8) \\ [\text{RPdCl}] \quad + \quad \text{RHgCl} \longrightarrow \text{R-R} \quad + \quad \text{HgCl}_2 \quad + \quad \text{Pd} \\ (9) \qquad \qquad (2) \qquad \qquad (8) \end{array}$$


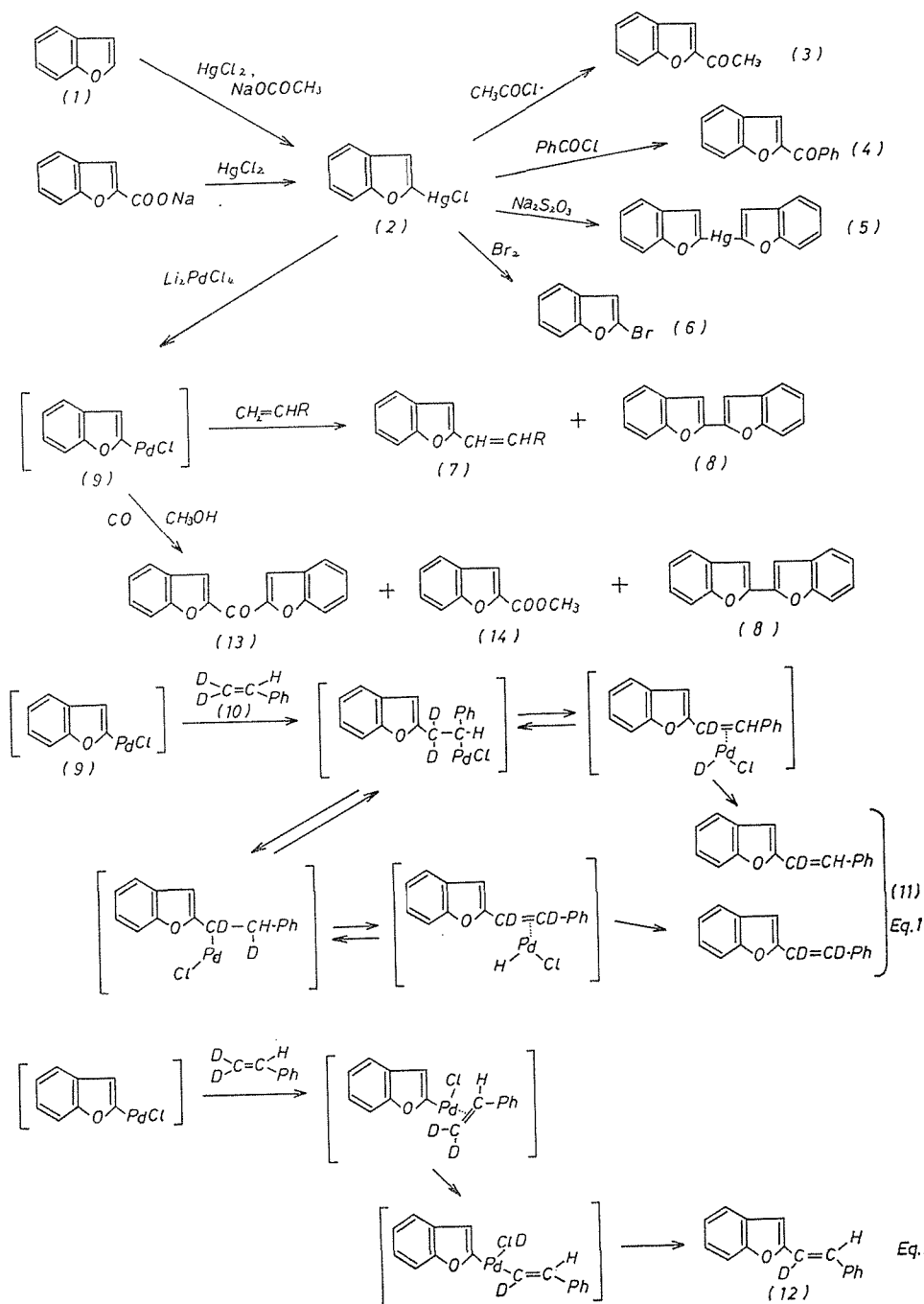
the reaction.⁹⁾ Moreover, we have reported that the ferrocenylation of olefins with ferrocenylpalladium chloride proceeds *via* a hydride shift.¹⁰⁾ Therefore, in order to study whether or not the hydride shift also occurs in the reaction of 2 with olefins, the reaction of 2 with styrene- β , β -d₂ (10) was performed in the presence of lithium chloropalladite.

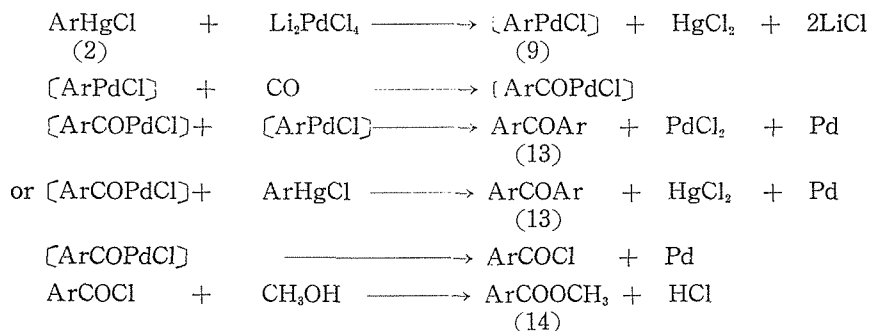
If the hydride shift occurs in the reaction of 2 with 10, the reaction will produce a mixture of mono- and di-deuterio-2-benzofurylstyrene (11), and the deuterium content of 11 will be 150% (Eq. 1). Contrary to this, according to the no hydride shift mechanism, the deuterium content of the product should be 100% (Eq. 2). The reaction of 2 with 10 resulted in the formation of monodeuterio-2-benzofurylstyrene derivative (12), indicating that the deuterium content is completely different from the case of the hydride shift (D-content = 150%). The result clearly confirmed that a loss of hydride-palladium species from the 2-benzofurylpalladium compound-olefin adduct involves the intermediate formation of a hydride-palladium π -complex and is much more likely than the readdition in the reverse direction.

Carbonylation of 2 with palladium salts. It has recently been found that palladium or palladium chloride can be used as a catalyst for the carbonylation reaction of various compounds:²⁾ olefins,¹¹⁾ dienes,¹²⁾ acetylene,¹³⁾ allyl halides,¹⁴⁾ and amines.^{15), 16)} Henry¹⁶⁾ has also reported that arylpalladium salts, prepared *in situ* from arylmercuric salts and palladium compounds, react with carbon monoxide to form arylcarboxylic acids and their derivatives. Moreover Heck¹⁷⁾ has described that diarylketones could be formed in moderate yields from arylmercuric salts and carbon monoxide with a palladium-salt catalyst. We have also described the carbonylation of 1,1'-bis-chloromercuriferrocene¹⁸⁾ and furan mercuric compounds¹⁹⁾ in the presence of palladium salt. In this report, we wish to report on the carbonylation reactions of 2 in methanol with palladium salt.

The carbonylation of 2 was carried out at 100°C under a carbon monoxide pressure of 50 atm in the presence of lithium chloropalladite in methanol; the main products were 2,2'-dibenzofurylketone (13) and methyl coumarilate (14), plus a small amount of 8. In the carbonylation of arylmercuric salts, the use of rhodium catalysts for the diarylketone has been reported.¹⁷⁾ However, in the carbonylation of 2, the use of rhodium trichloride as a catalyst did not bring about better results in the formation of 10 compared with the use of the palladium catalyst.

The mechanism of the formation of 13 from 2, as Heck pointed out in his carbonylation study,¹⁷⁾ probably involves the reaction of an acyl-palladium compound with 9 or 2. 14 is probably formed by side reaction.





Ar = 2-benzofuryl

Experimental

Analysis and materials. All melting points and boiling points are uncorrected. The infrared spectra were recorded by means of a Hitachi 215 IR spectrometer, while the NMR spectra were obtained by a Hitachi R-22 NMR spectrometer at 90 MHz in CDCl_3 , using tetramethylsilane as the internal standard. The mass spectra were obtained on a Hitachi RMU-6D mass spectrometer, using a direct inlet and an ionization energy of 70 eV.

The styrene- $\beta,\beta\text{-d}_2$ (10) was prepared from ethyl phenylacetate according to the method described by Schubert and Lamm.²⁰⁾ The following compounds were synthesized by the methods described in the literature: benzofuran (1), bp 173–174°C,²¹⁾ coumarilic acid, mp 190–193°C.²²⁾ The starting olefins were of commercial grade.

Preparation of 2-benzofurylmercuric chloride (2).

(a) *From benzofuran (1).* A solution of 54 g (0.2mol) of mercuric chloride in 800ml of water was added to 108.8g (0.4mol) of sodium acetate trihydrate in 400ml of water; the resulting solution was thoroughly chilled, and to it was added quickly 23.6g (0.2mol) of 1 in 120ml of alcohol. The mixture was allowed to stir at room temperature for five days, after which the deposit was filtered by suction, washed with alcohol, and dried. Mp 274–278°C (35g, 50% yield). The mercurial (2) was insoluble in most solvents.

Found: C, 27.31; H, 1.26%. Calcd for $\text{C}_8\text{H}_5\text{OHgCl}$: C, 27.19; H, 1.41%.

(b) *From coumarilic acid.* A solution of 16.2g (0.1mol) of the sodium coumarilate (prepared by dissolving the acid in one equivalent of sodium hydroxide) in 500ml of water was added to a solution of 27g (0.1 mol) of mercuric chloride in 500ml of water at room temperature. After one hour the mixture was boiled until the evolution of carbon dioxide was complete. On cooling, the mercurial was filtered and washed with alcohol. It weighed 22.5g

or 64% as based on the mercuric chloride. Mp 274–278°C.

Reaction of 2 with acetyl chloride. The mercury compound 2 (5 g) and acetyl chloride (30ml) were left for 5 days at room temperature, the mixture poured into water, treated with sodium carbonate, and extracted with ether, and the residue distilled at 52–60°C/8mm Hg, giving a volatile solid which after one recrystallization from cyclohexane melted at 69–71°C. The structure of the product was confirmed by the observation of the IR and NMR spectra and by comparing the retention time with that of 2-benzofuryl methyl ketone (3), which was prepared from 1, acetyl chloride, and stannic chloride.²³⁾

Reaction of 2 with benzoyl chloride. From 5 g of 2, 10g of benzoyl chloride and 500ml of ether, stirred for 24 hr, was obtained 0.8g of 2-benzofuryl phenyl ketone (4), mp 90–91°C, (lit.,²⁴⁾ mp 91°C).

Coupling of 2 to 2,2'-dibenzofurylmercury (5). To a solution of 50g of sodium thiosulfate in 200ml of water was added at once 35g of 2; the mixture was stirred vigorously at room temperature, and after 10 hr the precipitate was filtered to give a 90% yield of crude 2,2'-dibenzofurylmercury (5) which may be purified by recrystallization from a hot acetone-water solution and melts at 214°C.

Found: C, 44.05; H, 2.13%. Calcd for $C_{16}H_{10}O_2Hg$: C, 44.24; H, 2.30%

Reaction of 2 with bromine. A solution of bromine (4.8g) in 150ml of ether was added to a suspension of 2 (10.5g) in 100ml of ether. After the resulting solution was stirred for 10 hr at 0°C, the ether layer was washed successively with aqueous sodium bicarbonate and water, and was dried over anhydrous magnesium sulfate and evaporated to dryness. The residue was distilled at 220–224°C to give 2-bromobenzofuran (6) in 22% yield. The structure of the product was confirmed by the observation of the IR and NMR spectra and by comparing the retention time with that of the authentic sample²⁵⁾ (lit. bp 221–223°C).

Reaction of 2 with olefins. Lithium chloropalladite solutions were prepared by stirring 0.84g (20mmol) of anhydrous lithium chloride and 1.77g (10mmol) of palladium chloride overnight at room temperature in 100ml of the respective solvent except in the case of acetonitrile, where 10mmol instead of 20mmol of lithium chloride was used. To this lithium chloropalladite solution, a mixture of 10mmol of 2 and four times as much olefin was added, after which the mixture was stirred at room temperature for 12 hr. The products were isolated by filtration to remove a precipitated palladium and by distillation under reduced pressure to remove the solvent. The residue was dissolved in benzene and then was purified by column chromatography on neutral alumina. The structures of the products were confirmed by the mixed-melting-point determination with an authentic sample and by an observatin of

the IR and NMR spectra. The results are summarized in Table 1.

Reaction of 2 with styrene- β , β - d_2 (10). In an acetonitrile(100ml) of lithium chloropalladite (10mmol), a mixture of 10 mmol of 2 and 20 mmol of 10 was stirred for 12 hr at room temperature. After the separation of the precipitated palladium, and the evaporation of the solvent, the residual oil was separated by alumina chromatography. The first elution with benzene and the subsequent recrystallization from ethanol afforded colorless crystals which were identified as the 2-styrylbenzofuran- d_1 (12), mp 121—122°C, (45% yield). NMR spectrum: δ 6.62 (1) s furan ring proton on C₃, 6.89 (1) s —CD=CH—Ph, 7.14—7.65 ppm (9) m aromatic ring protons. The isotopic purity (97%) of 12 was calculated on the basis of a mass spectral analysis.

Further elution with chloroform and recrystallization from ethanol afforded colorless crystals which were identified as the 2,2'-dibenzofuryl (8), mp 194—195°C, (lit.²⁶) mp 194.5—195.5°C) (7% yield).

Carbonylation of 2. The lithium chloropalladite solution was prepared by stirring 0.84 g of lithium chloride and 1.77g of palladium chloride overnight at room temperature in 200ml of methanol. Into this lithium chloropalladite solution, 3.52g (10 mmol) of 2 was then carbonylated at 100°C under a carbon monoxide pressure (50 atm) for 6 hr with shaking; a pressure drop was thus observed. The products were isolated by filtering to remove a precipitated palladium and by distilling under reduced pressure to remove the solvent. The residue was dissolved in benzene and chromatographed on neutral alumina. The first elution with benzene and recrystallization from methanol afforded colorless crystals which were identified as the methyl coumarilate (14), mp 44°C, (37% yield) by a comparison of the IR and NMR spectra with those of an authentic sample (lit.²⁷) mp 44°C) and by a mixed-melting-point determination.

The second elution with benzene and recrystallization gave colorless crystals (mp 61—62°C) which were identified as 2,2'-dibenzofurylketone (13) (28% yield) by a study of the IR and NMR spectra. IR spectrum: 1640 (carbonyl), 880 (furan), and 730cm⁻¹ (1,2-disubstituted benzene ring). NMR spectrum: δ 6.71 (2) s furan ring protons on C₃ and C_{3'}, 7.12—7.66 ppm (8) m aromatic ring protons.

Found: C, 77.66; H, 3.81%. Calcd for C₁₇H₁₀O₃: C, 77.85; H, 3.84%.

Further elution with chloroform and recrystallization from ethanol afforded colorless crystals which were identified as 2,2'-dibenzofuryl (8), mp 194—195°C, by a comparison of the IR and NMR spectra with those of an authentic sample.²⁶⁾

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ベンゾフリル水銀化合物の研究

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アルコール-水の混合溶液中酢酸ナトリウムの存在でベンゾフランと塩化第二水銀とを反応させると塩化-2-ベンゾフリル水銀(2)を生ずる。このものはまたクマリル酸と塩化第二水銀との反応によっても生ずる。2をチオ硫酸ナトリウムで還元するとジ-2-ベンゾフリル水銀となり、塩化アセチルと反応させると2-ベンゾフリルメチルケトンを生ずる。塩化パラジウム酸リチウムの存在で種々のオレフィンと反応させると、少量の2,2'-ビベンゾフリルを伴い、2-ベンゾフリル置換オレフィン誘導体を生じた。さらにパラジウム塩の存在で、メタノール中一酸化炭素を反応させると、2,2'-ビベンゾフリルを伴いクマリル酸メチルエステルおよびジ-2-ベンゾフリルケトンを生じた。