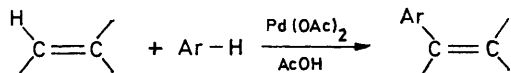


Novel Synthesis of β -Substituted β -Diphenylmethylstyrenes from β -Substituted β -Methylstyrenes in the Presence of Palladium(II) Acetate

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β -Substituted β -methylstyrenes react with benzene in the presence of palladium(II) acetate to produce the corresponding (*E*)- and/or (*Z*)- β -substituted β -diphenylmethylstyrenes in good yields. A mechanism involving a 2-substituted 3,3-diphenylpropene intermediate is suggested. The configurations of the products are discussed.

PALLADIUM(II) salts have recently attracted much attention in relation to their use in organic syntheses. Since Moritani *et al.*¹ reported the novel aromatic substitution of an olefin in the presence of palladium(II) salts, numerous reports of similar aromatic



substitution reactions have appeared. For example, similar arylation reactions involving use of arylmercury compounds,² triarylphosphines,³ and iodobenzenes,⁴ in

¹ (a) I. Moritani and Y. Fujiwara, *Tetrahedron Letters*, 1967, 1119; (b) M. Watanabe, M. Yamamura, I. Moritani, Y. Fujiwara, and A. Sonoda, *Bull. Chem. Soc. Japan*, 1974, **47**, 1035, and references therein.

² (a) R. F. Heck, *J. Amer. Chem. Soc.*, 1968, **90**, 5518; (b) H. A. Dieck and R. F. Heck, *ibid.*, 1974, **96**, 1133, and references therein.

the presence of palladium(II) salts have been described. Although extensive fundamental studies on these reactions have been carried out, their application in synthesis has not been extensively investigated. This paper reports the preparation of β -substituted β -diphenylmethylstyrenes from the corresponding β -methylstyrenes by using palladium(II) acetate.

We have previously reported the preparation of (*E*)- and (*Z*)- β -diphenylmethyl- β -nitrostyrene from β -methyl- β -nitrostyrene in the presence of palladium(II) acetate.⁵ This appeared to be the first example of diphenylation of an allylic methyl group brought about by palladium-

³ K. Kikukawa, T. Yamane, M. Takagi, and T. Matsuda, *J.C.S. Chem. Comm.*, 1972, 695.

⁴ T. Mizoroki, K. Mori, and A. Ozaki, *Bull. Chem. Soc. Japan*, 1971, **44**, 581.

⁵ K. Yamamura, S. Watarai, and T. Kinugasa, *Tetrahedron Letters*, 1972, 2829.

(II) acetate. It was then considered of interest to determine whether other β -substituted β -methylstyrenes also reacted with benzene to give the corresponding β -diphenylmethylstyrenes.

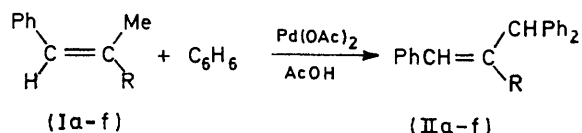
In general method of diphenylation, a mixture of the β -methylstyrene derivative and 3 mol. equiv. of palladium(II) acetate in acetic acid and large excess of benzene was refluxed until precipitation of metallic

Diphenylation of β -methylstyrenes in the presence of palladium acetate

β -Methylstyrene	R	Products	Yield ^a (%)	Found (Calc.) (%)			M.p. (°C)	(i) I.r. ^b (ν_{\max} /cm ⁻¹) and (ii) n.m.r. ^c (δ) spectra
				C	H	N		
(E)-(Ia)	NO ₂	(E)-(IIa)	37	79.85	5.35	4.4	151	(i) 1637, 1596, 1447, 1328, 825, 765, 695
		(Z)-(IIa) ^d	25	79.95	5.35	4.3	103	(ii) 8.25 (1H, s, vinyl), 7.32 (5H, s, Ph), 7.23 (10H, s, Ph), 5.87 (1H, s, -CH<)
(E)-(Ib)	CO ₂ H	(E)-(IIb)	30	84.05	5.8		204	(i) 1681, 1446, 1415, 1255, 806, 773, 692
		(Z)-(IIb)	28	84.2	5.85		163	(ii) 10.43br (1H, s, acid), 8.10 (1H, s, vinyl), 7.30 (5H, s, Ph), 7.22 (10H, s, Ph), 5.67 (1H, s, -CH<)
(E)-(Ic)	CO ₂ Me	(E)-(IIc)	27	84.15	6.1		86	(i) 1712, 1445, 1352, 1232, 1095, 735, 692
		(Z)-(IIc)	21	84.25	6.25		101	(ii) 7.93 (1H, s, vinyl), 7.28 (5H, s, Ph), 7.22 (10H, s, Ph), 5.63 (1H, s, -CH<), 3.57 (3H, s, Me)
(E)-(Id)	Bz	(E)-(IIId)	43	90.0	5.75		172	(i) 1723, 1495, 1447, 1368, 747, 698
		(Z)-(IIId)	23	89.9	5.75		133	(ii) 7.25 (10H, s, Ph), 7.22 (5H, s, Ph), 6.32 (1H, d, vinyl, <i>J</i> 1.5 Hz), 5.43 (1H, d, -CH<), 3.45 (3H, s, Me)
(E)-(Ie)	Ph	(E)-(IIe)	<i>d</i>	93.55	6.4		110	(i) 1653, 1592, 1487, 1247, 750, 715, 688
		(Z)-(IIe)	50	93.65	6.35		130	(ii) 7.80—7.20 (21H, m, Ph and vinyl), 5.75 (1H, s, -CH<)
(E)-(If)	C ₆ H ₄ ·OMe(<i>p</i>)	(E)-(IIIf)	<i>d</i>	89.3	6.5		120	(i) 1640, 1495, 1237, 956, 737, 713, 695
		(Z)-(IIIf)	45	89.25	6.65		115	(ii) 7.87—7.03 (20H, m, Ph), 6.59 (1H, d, vinyl, <i>J</i> 1.5 Hz), 5.42 (1H, d, -CH<)
(E)-(Ia)	NO ₂	(E)-(VIa)	39	77.7	5.85 ^e	4.3	151	(i) 1595, 1485, 1270, 1240, 1173, 1027, 690
		(Z)-(VIa)	25	77.35	5.75	4.25	103	(ii) 7.25—6.52 (19H, m, ArH), 6.85 (1H, s, vinyl), 5.72 (1H, s, -CH<), 3.67 (3H, s, Me)

^a Yields are of isolated and purified products. ^b KBr disc. ^c Solvent CDCl₃; Me₄Si as internal standard. ^d Not isolated. ^e Estimated D as 2H.

palladium ceased. The results and the physical data of the products are given in the Table. β -Methylstyrene itself gave α -methylstilbene, the product of



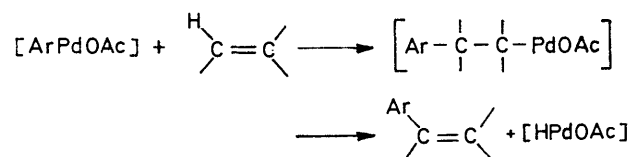
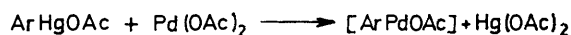
normal phenylation, in 24% yield.⁶ However, the β -substituted β -methylstyrenes (Ia-f) gave the corresponding β -diphenylmethylstyrenes (IIa-f) in 45–66% yields, in one step, along with small amounts of biphenyl. The structures of the diphenylation products were determined from their i.r., u.v., and n.m.r. spectra and elemental analyses. Moreover, the nitro-derivative (*E*)-(Ia) was identical with a sample prepared independently by Knoevenagel condensation of benzaldehyde and 2-nitro-1,1-diphenylethane.

The reactivity of the β -methylstyrenes was apparently not influenced much by the polarity of the β -substituents [*cf.* compounds (Ie and f)]. Though the use of re-oxidation catalysts such as silver acetate⁷ enabled the reaction to proceed catalytically with respect to palladium acetate, it was sometimes difficult to separate the products because of the presence of thick slurries of unchanged palladium acetate. Except in the cases of the α -methylstilbene derivatives (Ie and f), both (*E*)- and (*Z*)-isomers of the products were isolated. In the cases of (Ie and f), although only the *cis*-stilbene derivatives (*Z*)-(IIe) and (*Z*)-(IIf) were isolated the presence of traces of the (*E*)-isomers was confirmed by n.m.r. spectroscopy. Compounds (*E*)-(IIe) and (*E*)-(IIf) were readily prepared by photoisomerization of the (*Z*)-isomers. The geometrical configuration of the diphenylated products was determined mainly by their n.m.r. spectra (Table). For compounds (IIa–d), each of which has a β -substituent exercising a large diamagnetic anisotropy effect, the (*E*)-isomer, which has the vinyl proton and the β -substituent *cis* to each other, is expected to show a vinyl proton signal at lower field than the (*Z*)-isomer. Indeed, as previously reported,⁵ *trans*- β -nitrostyrenes, in which the nitro group and the vinyl proton are *cis* show the vinyl proton signal at δ 8.02–8.36, and *cis*- β -nitrostyrenes show the corresponding signal at δ 6.13–7.56. In the cases of compounds (IIa–d) the vinyl proton chemical shift differences are large enough (*ca.* 1.6 p.p.m.) for assignment of configuration. However the corresponding differences for compounds (IIe and f) are only 0.6 p.p.m., insufficient for definitive assignments. This problem was solved by the observation that the (*Z*)-isomers of (IIa–d) showed long-range coupling between the vinyl proton and the methine proton whereas the (*E*)-isomers did not; thus the compounds isolated from the diphenylation reactions of (Ie) and (If), which did show such a long-range coupling, were identified as the (*Z*)-isomers. The photoisomerisation products showed

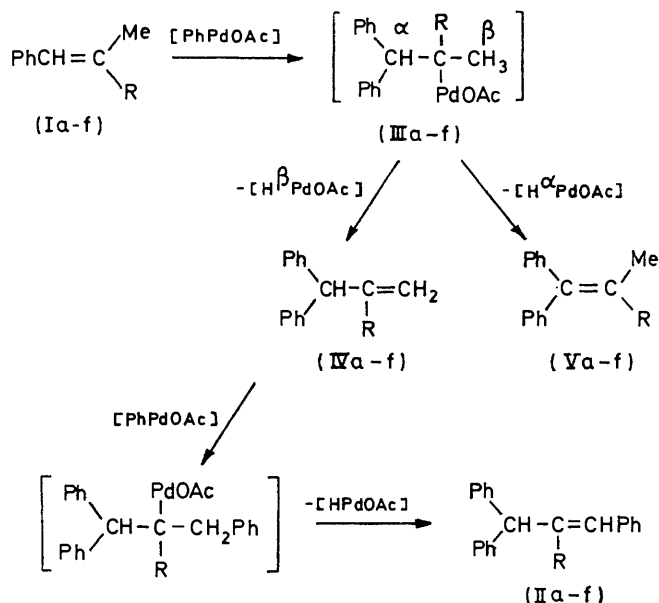
⁶ K. Yamamura, S. Watarai, and T. Kinugasa, *Chem. Letters*, 1973, 91.

no long-range coupling. U.v. data supported these configurational assignments.

For the formation of (IIa) from (Ia), we have previously reported the isolation of the intermediate 2-nitro-1,1-diphenylpropene.⁵ However the isolation of this compound was not reproducible; instead, when (Ia) was treated with an equimolar amount of palladium acetate in benzene and acetic acid, a small amount of 2-nitro-3,3-diphenylpropene (IVa) was obtained. This was identified from its i.r., u.v., and n.m.r. spectra and independent preparation. When (IVa) was treated with benzene in the presence of palladium acetate in order to confirm that it was an intermediate, compound (IIa) was produced. However when 2-nitro-1,1-diphenylpropene, prepared independently, was treated with benzene in the presence of palladium acetate, no



SCHEME 1



SCHEME 2

evidence for the production of compound (IIa) was obtained.

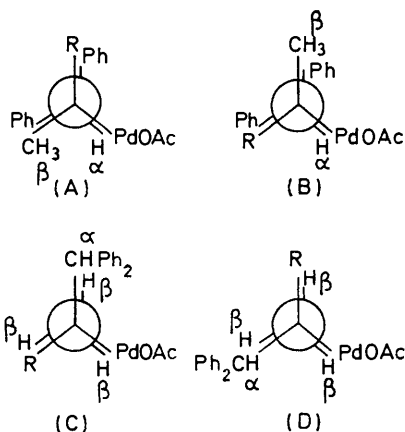
Heck has suggested a stereospecific reaction mechanism involving *cis*-addition of arylpalladium acetate to the olefinic double bond and subsequent *cis*-elimination of hydridopalladium acetate, for the arylation of an olefin by an arylmercury compound and palladium acetate⁸ (Scheme 1). Application of this mechanism

⁷ Y. Fujiwara, I. Moritani, M. Matsuda, and S. Teranishi, *Tetrahedron Letters*, 1968, 3863.

⁸ R. F. Heck, *J. Amer. Chem. Soc.*, 1969, **91**, 6707.

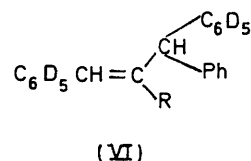
to the diphenylation reactions leads to the pathway shown in Scheme 2. As the first step phenylpalladium acetate, produced *in situ* from benzene and palladium acetate,⁹ attacks the β -methylstyrene to give the intermediate complex (III) (this could not be isolated). Subsequent *cis*-elimination of $H^{\beta}PdOAc$ affords the intermediate (IV). Similar *cis*-addition of phenylpalladium acetate to (IV) and subsequent *cis*-elimination of hydridopalladium acetate affords the product (II). If *cis*-elimination of $H^{\alpha}PdOAc$ occurs, the product should be (V). It is considered that (IV) is less stable thermodynamically than (V) because the former is the terminal olefin. For *cis*-elimination of $H^{\alpha}PdOAc$ and $H^{\beta}PdOAc$ from the intermediate complex (III), the favourable conformations are (A) and (B), and (C) and (D), respectively. It is clear that the former are more unstable than the latter because of steric interaction. Consequently, it can be assumed that (IVa—f) are formed preferentially.

A mechanism involving direct diphenylation of the methyl group is not thought to be reasonable. If the mechanism of Scheme 2 is correct, use of hexadeuterio-benzene instead of benzene as solvent and reactant should give products of the type (VI) instead of (II).



In fact, when (Ia) was treated with C_6D_6 in the presence of palladium acetate under similar conditions, both (*E*)- and (*Z*)-isomers of (VIa) were obtained instead of (II) (see Table). These products were identified as follows. The n.m.r. spectrum of (*E*)-(IIa) shows phenyl group signals at δ 7.32 (5H) and 7.23 (10H). However (*E*)-(VIa) shows no peak at δ 7.32 and a singlet

δ -proton peak at δ 7.23. In a similar manner, the structure of (*Z*)-(VIa) was determined.



Thus these diphenylation reactions are not 'direct' diphenylations of the allylic methyl group but are stepwise reactions.

EXPERIMENTAL

I.r. spectra were recorded with a Nihonbunko DS-402G spectrometer, and n.m.r. spectra with a Varian A-60 spectrometer ($CDCl_3$ as solvent and tetramethylsilane as internal standard).

Materials.—Palladium acetate was prepared according to the method of Stephenson *et al.*⁹ β -Methyl- β -nitrostyrene (Ia),¹⁰ α -methylcinnamic acid (Ib),¹¹ and α -methylchalcone (Id)¹² were prepared as described in the literature. Methyl α -methylcinnamate (Ic) was prepared by esterification of (Ib). The α -methylstilbene derivatives (Ie and f) were prepared by a procedure similar to that described for the preparation of triphenylethylene.¹³

General Procedure for the Diphenylation of β -Methylstyrenes.—A mixture of the β -methylstyrene (0.01 mol) and palladium acetate (0.03 mol) in benzene (150 ml) and acetic acid (40 ml) was refluxed with stirring for 20 h. After separation of palladium metal, the mixture was washed with water and evaporated *in vacuo*. The residue was chromatographed over silica gel. Elution with *n*-hexane gave a small amount of biphenyl; further elution with *n*-hexane–benzene (1 : 1) gave the β -diphenylmethylstyrene. If some of the starting palladium acetate was unchanged, reduction to palladium metal by addition of ethanol to the mixture before washing with water facilitated isolation of the products.

Photoisomerization of (*Z*)- β -Diphenylmethyl- β -phenylstyrene [(*Z*)-(IIe)].—A solution of (*Z*)-(IIe) in benzene was irradiated with a high-pressure mercury lamp for 4 h, and evaporated *in vacuo*. Chromatography over silica gel and fractional crystallization from ethanol gave the (*E*)-isomer, m.p. 110°.

Under similar conditions (*Z*)-(IIf) gave (*E*)-(IIf), m.p. 120°.

I thank Professor S. Watarai for discussions, and Miss M. Nishinaka for i.r. measurements and elemental analyses. I also thank Miss M. Sugiura, Kobe Women's College of Pharmacy, for n.m.r. measurements.

[4/2049 Received, 4th October, 1974]

⁹ T. A. Stephenson, S. M. Morehouse, A. R. Powell, J. P. Heffer, and G. Wilkinson, *J. Chem. Soc.*, 1965, 3632.

¹⁰ H. B. Hass, A. G. Susie, and R. L. Heider, *J. Org. Chem.*, 1950, 15, 8.

¹¹ W. J. Gensler and E. Berman, *J. Amer. Chem. Soc.*, 1958, 80, 4949.

¹² T. Yokoyama and F. Nohara, *Bull. Chem. Soc. Japan*, 1965, 38, 1498.

¹³ H. Adkins and W. Zartman, *Org. Synth.*, 1943, Coll. Vol. II, p. 606.