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Orthopalladated phosphinite complexes as high-activity catalysts for the Suzuki reaction †

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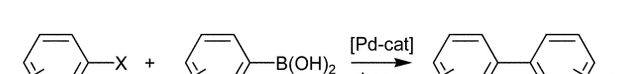
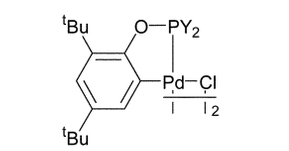
The synthesis of a range of phosphinite ligands $PR_2(OAr)$ (R = Ph, ^{i}Pr), their simple complexes with palladium(II) and their palladacyclic complexes has been investigated. The crystal structure of one of the palladacyclic complexes, $[\{Pd(\mu_2\text{-}Cl)\{\kappa^2\text{-}P,C\text{-}P^iPr_2(OC_6H_2\text{-}2,4\text{-}^tBu_2)\}\}_2]$, has been determined. The palladacyclic complexes show extremely high activity in the Suzuki coupling of aryl bromide substrates with phenylboronic acid and can also be used with alkylboronic acid substrates. A comparison of the phosphinite-based catalysts with equivalent phosphite- and phosphine-based systems highlights their superior activity. The orthometallation of the phosphinite ligand in the pre-catalyst appears to be crucial for optimal activity. While the phosphinite palladacycles are only moderately active in the coupling of activated and non-activated aryl chloride substrates, their tricyclohexylphosphine adducts prove to be highly active in the coupling of the deactivated substrate, 4-chloroanisole. This high activity compared with other palladacyclic systems is explained in terms of catalyst longevity. The orthometallated precatalysts appear to undergo a reductive activation process to generate zerovalent active catalysts *via* reductive elimination of the orthometallated ring with a phenyl introduced by the boronic acid. This implies that the true active catalysts contain 2-arylated ligands. Catalysts formed with such 2-arylated ligands tend to show markedly higher activity than their parent ligands.

Introduction

The coupling of aryl halides with aryl boronic acids, the Suzuki reaction (Scheme 1), is one of the most powerful and versatile methods for the synthesis of biaryls.[1] Traditional palladium-based catalysts such as $[Pd(PPh_3)_4]$ or catalysts formed *in situ* from a triarylphosphine and an appropriate palladium source suffer from two major limitations. The first is that these catalysts have to be used in comparatively high loadings (typically a few mol% Pd). This is problematic because currently for application in fine chemicals and pharmaceuticals processes the maximum acceptable palladium contamination of the product is in the low ppm region. This necessitates expensive clean-up procedures. In addition the high cost of palladium may make the use of coupling chemistry prohibitively expensive. The second major problem is that traditional catalysts show, at best, limited activity with aryl chlorides – particularly deactivated (electron rich) aryl chlorides – due to the high C–Cl bond strength.[2] These substrates are of particular interest as they tend to be cheaper and more readily available than their bromide or iodide counterparts. Therefore there has been major interest in developing catalysts that can be used in very low loadings and ideally that activate aryl chloride substrates. Palladacyclic complexes have played a particular role in this regard.[3] We have found that orthopalladated triarylphosphite or phosphinite complexes of the types **1** and **2** show excellent activity in the Suzuki coupling of aryl bromides,[4] and that the tricyclohexylphosphine adducts **3** are highly effective for the coupling of deactivated aryl chloride substrates.[5] We now report in full the synthesis of orthopalladated phosphinite complexes and their use in the Suzuki coupling reactions of both aryl bromide and aryl chloride substrates.

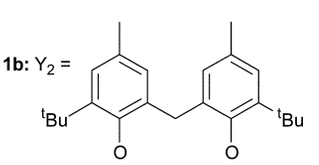


Scheme 1 The Suzuki biaryl coupling reaction.

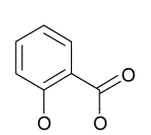


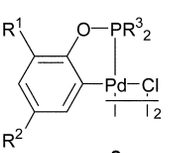
1a: Y = OC_6H_3-2,4-^{t}Bu$_2$

1b: Y_2 =



1c: Y_2 =





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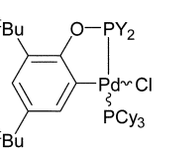

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Results and discussion

Synthesis of phosphinite ligands and complexes

The phosphinite ligands **4** are synthesised by reaction of the appropriate phenols with chlorophosphines in the presence of triethylamine in toluene at reflux temperature (Scheme 2). In the case of the triarylphosphinite ligands **4a**–**i** (Table 1) simple

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Scheme 2 (i) $ClPR^3_2$, Et_3N, toluene, 18 h.

† Based on the presentation given at Dalton Discussion No. 6, 9–11th September 2003, University of York, UK.

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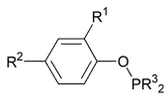
Table 1 Selected data for phosphinite ligands

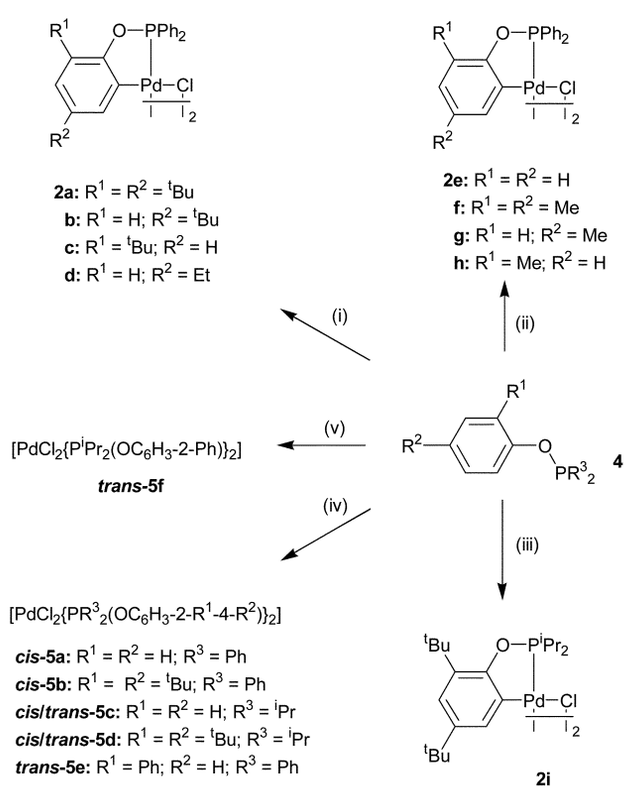


Compound no.	R^1	R^2	R^3	Yield (%)	$^{31}P–\{^1H\}$ NMR δ (ppm)[a]	$\Delta\delta$ compared with $R_2P(OPh)$ (ppm)
4a	H	H	Ph	97	111.2	0
4b	H	Me	Ph	96	111.8	0.6
4c	H	Et	Ph	97	111.4	0.2
4d	H	^{t}Bu	Ph	99	110.9	−0.3
4e	Me	H	Ph	95	110.1	−1.1
4f	Me	Me	Ph	95	110.3	−0.9
4g	^{t}Bu	H	Ph	98.5	108.6	−2.6
4h	^{t}Bu	^{t}Bu	Ph	98	108.5	−2.7
4i	Ph	H	Ph	96	113.3	2.1
4j	H	H	^{i}Pr	89	149.0	0
4k	H	Me	^{i}Pr	92	149.6	0.6
4l	H	Et	^{i}Pr	97	149.4	0.4
4m	H	^{t}Bu	^{i}Pr	94	148.9	−0.1
4n	Me	H	^{i}Pr	94	144.5	−4.5
4o	Me	Me	^{i}Pr	95	144.3	−4.7
4p	^{t}Bu	H	^{i}Pr	96	138.5	−10.5
4q	^{t}Bu	^{t}Bu	^{i}Pr	96	138.4	−10.6
4r	Ph	H	^{i}Pr	82	151.5	2.5

[a] $CDCl_3$, 121.5 MHz, 25 °C.

filtration of the cooled reaction mixture to remove precipitated triethylamine hydrochloride followed by removal of the solvent gives the products cleanly. In the case of the diisopropylphosphinite ligands **4j**–**r** it is first necessary to add petroleum ether (bp = 60–80 °C) to ensure complete precipitation of the ammonium salt. If this step is not taken then the product ligands are contaminated by triethylamine hydrochloride, which prevents the formation of palladacyclic complexes.[6] Table 1 shows the $^{31}P–\{^1H\}$ NMR data for the range of phosphinite ligands synthesised. When the ^{31}P chemical shifts of the ligands are compared then it can be seen that those for the $^iPr_2P(OAr)$ ligands are shifted downfield with respect to those for the analogous $Ph_2P(OAr)$ ligands. A closer inspection shows that while variation in the substitution of the 4-position of the aryloxide ring has little or no effect on the ^{31}P signal, increase in the steric bulk of alkyl groups in the 2-position leads to an upfield shift. This trend is particularly pronounced in the case of the diisopropylphosphinites. By contrast the introduction of a 2-phenyl substituent leads to a downfield shift. In general, variation in size of simple triarylphosphites has very little effect on the chemical shift as exemplified by $P(OPh)_3$ and $P(OC_6H_3$-2,4-$^tBu_2)_3$ which have ^{31}P NMR δ values of 129 and 131 ppm respectively. By contrast variation in the size of substituents in phosphines can have a profound effect. It seems that in the case of phosphinites an intermediate position is adopted; steric variation leads to significant change in δ, but in a predictable fashion.

Having synthesised a range of phosphinite ligands we then turned our attention to generating a representative range of palladium adducts and palladacyclic complexes. Providing there is an ethyl or larger group in either the 2- or 4-position of the aryloxide residue, then complexes with orthopalladated $PPh_2(OAr)$ ligands can be readily formed by heating the ligand with one equivalent of palladium chloride in toluene (Scheme 3). If the largest group in either the 2- or 4-position is a methyl then it becomes necessary to use $[PdCl_2(NCMe)_2]$ as the palladium source. The palladacyclic complex of the diisopropylphosphinite ligand **4q**, complex **2i**, is best prepared by heating the ligand with palladium dichloride in 1,4-dioxane. The ^{31}P NMR spectra of the complexes with orthopalladated $PPh_2(OAr)$ ligands, complexes **2a**–**h**, all show two peaks in the range 151.1–157.5 ppm indicating that both the *cis* and *trans* isomers are present, as seen with orthopalladated triarylphosphites.[7,4c] The diisopropylphosphinite complex **2i** shows



Scheme 3 Conditions: (i) $PdCl_2$, toluene, Δ, 18 h. (ii) $[PdCl_2(NCMe)_2]$, THF, Δ, 18 h. (iii) $PdCl_2$, 1,4-dioxane, Δ, 18 h. (iv) 0.5 $[PdCl_2(NCMe)_2]$, CH_2Cl_2, r.t. 4 h. (v) 0.5 $[PdCl_2(NCPh)_2]$, toluene, Δ, 18 h.

two peaks at δ 203.4 and 202.7 ppm in the ^{31}P NMR spectrum again indicating the presence of both *cis* and *trans* isomers.

The crystal structure of complex **2i** has been determined and the molecule is shown in Fig. 1. As can be seen it adopts the *trans*-configuration in the solid state. The P1–Pd1 and C1–Pd1 bond lengths and the P1–Pd1–C1 bond angle are essentially identical to those reported previously for complex **1** (Y = OC_6H_3-2,4-$^tBu_2$).[4a] By contrast both of the Pd–Cl bond lengths of **2i** are longer and the Cl1–Pd1–Cl1^i angle substantially more obtuse.

As well as palladacyclic complexes we also produced the non-orthometallated complexes *cis*-$[PdCl_2(\mathbf{4})_2]$, **5**, by reaction of the

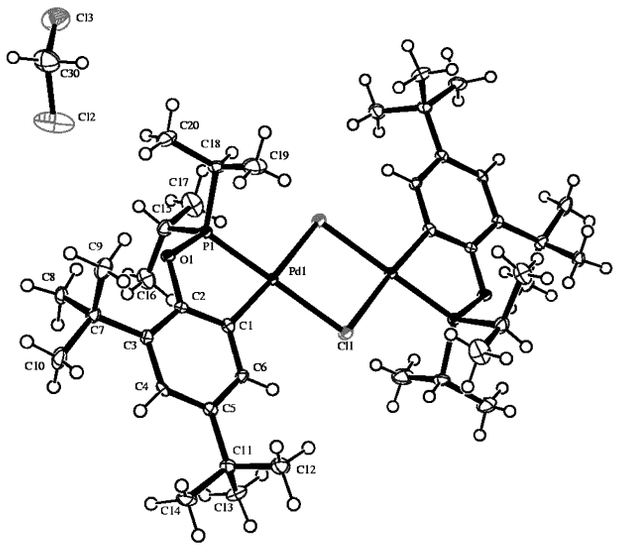
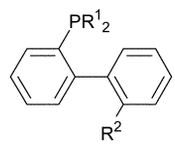


Fig. 1 Molecular structure of complex **2i**. Selected interatomic lengths (Å) and angles (°): Pd1–C1 2.012(2), Pd1–P1 2.1686(6), Pd1–Cl1 2.4313(6), Pd1–Cl1^{i} 2.4332(6); P1–Pd1–C1 80.24(7), P1–Pd1–Cl1^{i} 95.83(2), C1–Pd1–Cl1 97.72(7), Cl1–Pd1–Cl1^{i} 86.13(2), P1–Pd1–Cl1 176.87(2), C1–Pd1–Cl1^{i} 175.73(7).

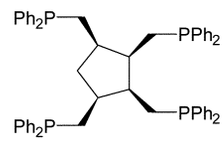
appropriate ligands with $[PdCl_2(NCMe)_2]$ in dichloromethane at room temperature. The synthesis of complex *cis*-**5a** using this method has been reported previously.[8] When the reaction of **4h** with $[PdCl_2(NCMe)_2]$ is left to stir for 4 hours the complex **5b** is obtained exclusively as the *cis* isomer, as indicated by the presence of two ν(Pd–Cl) peaks at 328 and 307 cm^{-1} in the IR spectrum. By contrast, we have previously found that when this reaction is left for only 1 hour then the product is exclusively *trans*.[8] This indicates that the kinetic product is the *trans* isomer while the thermodynamic product is the *cis* isomer. The latter is preferred electronically as the π-acidic phosphinite ligands are *trans* to the π-basic chlorides. Under the longer reaction conditions the complexes **5c** and **5d** are formed as mixtures of isomers. Previously we found that reactions between $[PdCl_2(NCMe)_2]$ and ligands **4j** and **4q** stirred for only 1 hour gave mixtures of several compounds.[8] The *o*-biphenyl substituted triarylphosphinite ligand **4i** reacts with $[PdCl_2(NCMe)_2]$ to give only the *trans* isomer, presumably due to the bulk of the ligand. The synthesis of the diisopropyl-phosphinite-containing analogue **5f** is achieved by heating the ligand **4r** with $[PdCl_2(NCPh)_2]$ in toluene at reflux temperature.

Phosphinite complexes as catalysts for the Suzuki reaction

(a) The coupling of aryl boronic acids. Orthopalladated diphenyl- and diisopropyl-phosphinite complexes are excellent catalysts for the Suzuki coupling of aryl bromide substrates at very low catalyst loadings.[4b] Table 2 summarises the coupling of a range of aryl bromides with phenylboronic acid. In all cases the reactions were performed in toluene with potassium carbonate acting as base. These conditions have not been optimised. The complexes **2a** and **2i** prove to be extremely active catalysts for both the 'easy to couple' substrate 4-bromoacetophenone and the more challenging, electronically deactivated substrate 4-bromoanisole. To the best of our knowledge, the activity shown by the catalyst mixture of **2i** and one equivalent of added ligand **4q** (entry 12) is the highest reported for any Suzuki reaction – giving over five times higher turnover number (TON, mol product/mol Pd) than for the analogous reaction catalysed by palladium complexes of the phosphine ligands **6**.[9] By contrast, the triarylphosphite-containing palladacycle **1a** shows a maximum TON of 58.5 million in this reaction.[4c] More importantly the maximum TON with the electronically deactivated substrate 4-bromoanisole (entry 9) is 3.5 times higher at a lower temperature and after a much shorter reaction time than that obtained with the previous best catalyst – one formed *in situ* from the tetraphosphine ligand **7**.[10] High activities are also seen with the sterically hindered substrates 2-bromotoluene and 2-bromo-*m*-xylene (entries 13 and 14).



6: R^1 = Cy, ^{t}Bu
R^2 = H, Me, ^{i}Pr, NMe_2



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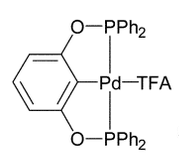
The diisopropylphosphinite-containing catalyst **2i** generally shows higher activity than the diphenylphosphinite-containing analogue **2a**, presumably due to the greater electron donor ability of the dialkylphosphinite ligand and/or its greater steric bulk. The observation that **2a** seems to show little difference in activity in the coupling of phenylboronic acid with either 4-bromoacetophenone or 4-bromoanisole at the same catalyst loadings (compare entries 1 and 2 with 3 and 4) indicates that, in this case, the oxidative addition of the aryl bromide is probably not the rate-determining step in the catalytic cycle. Comparing entries 3 and 7 it can be seen that decreasing the steric profile of the metallated ring has a deleterious effect on the performance of the catalysts, with complex **2e** showing much lower activity. Interestingly, complex **2e** still shows substantially higher activity than the notionally related complex **8** in the same reaction under the same conditions.[11]



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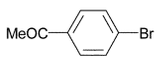
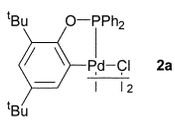
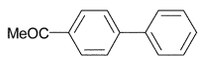
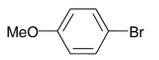
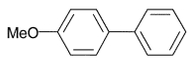
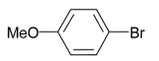
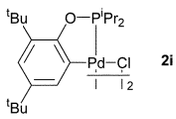
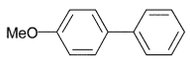
In contrast with the extraordinary results obtained with the deactivated aryl bromide 4-bromoanisole, complex **2i** proves to be a very poor catalyst when 4-chloroanisole is used as a substrate. However when the non-activated or activated aryl chloride substrates 4-chlorotoluene, 4-chloronitrobenzene, 4-chlorobenzaldehyde or 4-chloroacteophenone are employed then reasonable activity results at 1 mol% Pd loading (entries 17–19). In these cases caesium carbonate was used as the base and DMA as the solvent. Even under these modified conditions the performance of the catalyst **2i** with the deactivated substrate 4-chloroanisole is poor (entry 16). Gibson, Cole-Hamilton and co-workers have prepared the structurally related complex **9a** and tested its activity in the Suzuki coupling of both aryl bromides and chlorides.[12] In both instances it appears, from a comparison of their results with those in Table 2, that the replacement of the oxygen in the palladacyclic ring of complexes of the type **2** with a methylene group is deleterious to the overall performance of the catalysts. In addition the authors found that when 4-chlorobenzaldehyde is used as a substrate in the coupling with phenylboronic acid then the product is contaminated with substantial amounts of 1-(4-chlorophenyl)-1-phenylmethanol and 1,4-biphenyl-1-phenylmethanol. We do not observe these side-products when complex **2i** is used as the catalyst.

In order to perform a more accurate comparison of phosphinite ligands with analogous benzylphosphine-containing systems and with related triarylphosphite ligands, $P(OAr)_3$, and also to see whether orthometallation is important, we studied the coupling of 4-bromoanisole with phenylboronic acid catalysed by a range of catalysts. These catalysts fall into three classes: preformed dimeric palladacycles of the types **1** and **2**, preformed complexes of the type $[PdCl_2(L)_2]$ and catalysts formed *in situ* from palladium bis(dibenzylideneacetone) and

Table 2 Suzuki coupling of phenylboronic acid with aryl bromides and chlorides catalysed by orthopalladated phosphinite complexes.[a]

Entry	Aryl halide	Catalyst	Loading (mol% Pd)	Product	Conversion (%)[a]	TON
1		 **2a**	0.0001		90	900,000
2			0.00001		20	2,000,000
3			0.0001		85	850,000
4			0.00001		26	2,600,000
5		 **2i**	0.0001		91	910,000
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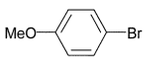
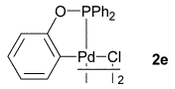
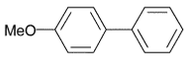
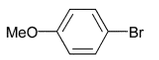
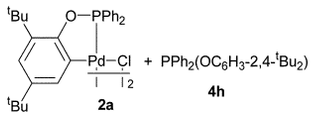
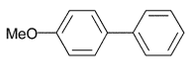
7		 **2e**	0.0001		29	290,000
8		 **2a** + **4h**	0.0001		100	1,000,000
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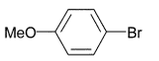
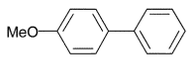
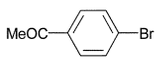
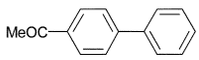
10			0.00001		50	5,000,000
11			0.000001[b]		100	100,000,000
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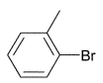
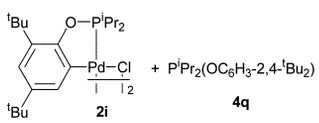
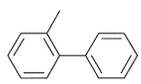
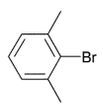
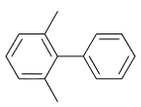
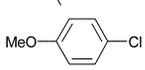
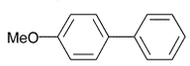
13		 **2i** + **4q**	0.001		100	100,000
14			0.001		48	48,000
15			1.0		6	6
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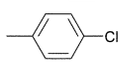
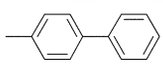
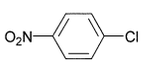
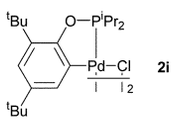
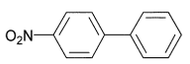
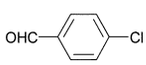
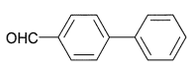
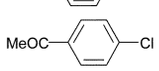
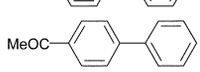
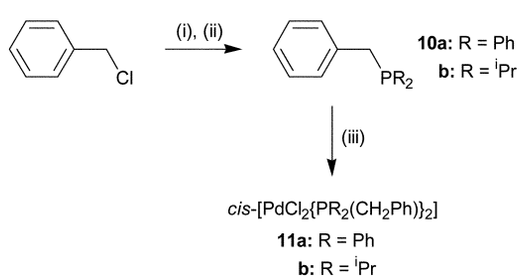
17			1.0[c]		76	76
18		 **2i**	1.0[c]		56	56
19			1.0[c]		100	100
20			1.0[c]		31	31

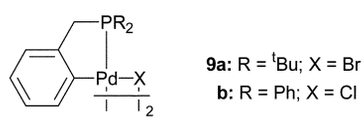
[a] *Reaction conditions:* aryl halide (10.0 mmol), $PhB(OH)_2$ (15.0 mmol), K_2CO_3 (20 mmol), toluene (30 mL), 130 °C (external temp., internal temp. approx 110 °C), 18 h. [b] 24 h reaction time. [c] Cs_2CO_3, DMA, 110 °C.

the appropriate ligand, L. The known ligand $PPh_2(CH_2Ph)$, **10a**, the new ligand $P^iPr_2(CH_2Ph)$, **10b**, and the complexes *cis*-$[PdCl_2\{PR_2(CH_2Ph)\}_2]$, **11** (**a:** R = Ph, **b:** R = ^{i}Pr) were prepared as shown in Scheme 4.



Scheme 4 Conditions: (i) Mg, Et_2O, 0 °C to r.t., 2 h. (ii) $ClPR_2$, 0 °C to r.t., 18h. (iii) $[PdCl_2(NCMe)_2]$, CH_2Cl_2, r.t., 30 min.

The complex **9b** was prepared by a literature method.[13] We were unable to prepare an analogous complex with R = ^{i}Pr using either the method for the formation of **9a** or that for the synthesis of **9b**.



4-Bromoanisole was chosen as the test substrate for the Suzuki coupling because it is electronically deactivated and therefore gives a better measure of optimal catalyst performance than more activated examples. The coupling reactions were performed at several catalyst loadings in the range 0.001–0.00001 mol% Pd in order to ascertain the maximum TON that these systems can give. The maximum TONs obtained are

summarised in Fig. 2. As can be seen in all cases, regardless of the ligand, the preformed complexes $[PdCl_2(L)_2]$ fared least well. Much better results are obtained when the catalysts are formed *in situ* from palladium bis(dibenzylideneacetone) and two equivalents of the ligand. Dibenzylideneacetone (dba) can be a highly tenacious ligand for Pd(0), which competes effectively with incoming substrates.[14] Indeed we previously found $[Pd_2(dba)_3]$ to be a poor precursor for PCy_3-containing catalysts for the Suzuki coupling of aryl chlorides.[15] It is possible that here the ligands used are sufficiently π-acidic to compete effectively with dba-coordination, thus displacing it from the coordination sphere and limiting competitive inhibition. Changing from the Pd-dba/2L systems to preformed phosphite-containing palladacycles of the type **1** does not give a particularly large increase in performance. By contrast a huge increase in activity is observed for the orthopalladated phosphinite ligands. This demonstrates that, in the case of the phosphinite ligands, orthometallation of the pre-catalyst is highly important. The possible role of the orthometallation is discussed later.

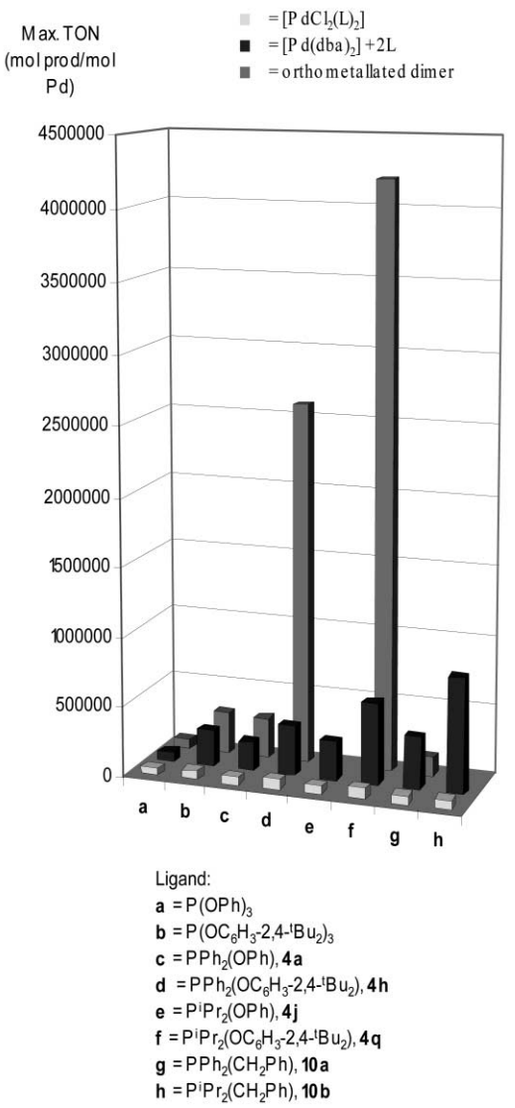


Fig. 2 Suzuki coupling of $PhB(OH)_2$ with 4-BrC_6H_4OMe with a variety of catalyst precursors and ligands. Conditions are the same as those used in Table 2 for aryl bromides.

It is also apparent that the phosphinite-based palladacycles show far higher activity than related phosphite complexes, at least under these conditions. Since it seems that the rate-determining step is not oxidative addition of the aryl bromide, it might be anticipated that the use of π-acidic ligands would increase the rate of catalysis which implies triarylphosphite ligands should be better. However if the ligands are *too* π-acidic then the palladium centre may become too electron deficient, tipping the rate-determining step to oxidative addition. Indeed, unlike with the phosphinite-containing palladacycle **2a**, which does not show an enormous difference in activity between 4-bromoanisole and 4-bromoacetophenone under identical conditions, there are two orders of magnitude difference in maximum TON with these substrates when the phosphite-containing complex **1a** is used as a catalyst.[4c] This suggests that, in the case of triarylphosphite-based palladacycles, oxidative addition *is* rate-determining. Thus the phosphinite catalysts represent the right balance of electronics – sufficiently π-acidic to facilitate both the nucleophilic attack of the boronate[16] and the reductive elimination of the product without unduly disfavouring oxidative addition.

(b) The coupling of alkyl boronic acids. There has recently been increasing interest in the use of alkylboronic acids in coupling reactions.[17] We wondered whether the orthopalladated phosphinite complexes **2** would act as effective catalysts in such processes. A brief solvent/base optimisation study was performed for the use of complex **2i** in the coupling of butylboronic acid and 4-bromoanisole, the results of which are summarised in Fig. 3. As can be seen, the best conversion is obtained with K_3PO_4 in 1,4-dioxane and these conditions were used for the remainder of the study, the results of which are summarised in Fig. 4. For comparison purposes, selected data obtained previously with $P(OAr)_3$ and PCy_3 are included.[4c]

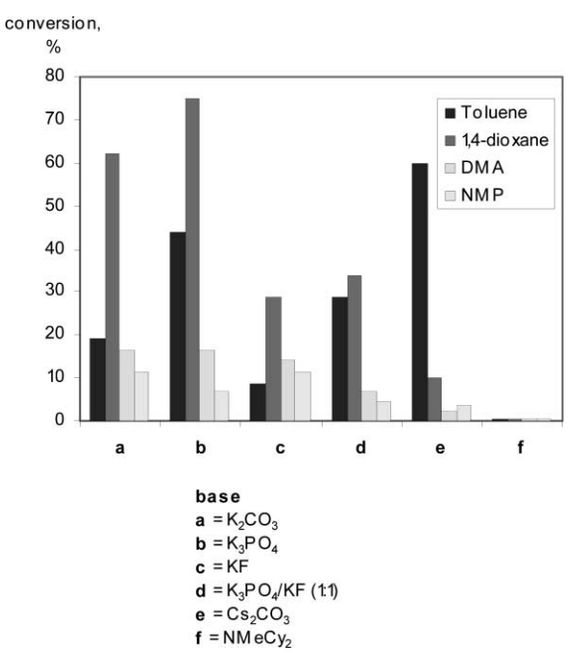


Fig. 3 Solvent/base optimisation in the coupling of *n*-butylboronic acid with 4-bromoanisole. Conditions: 4-BrC_6H_4OMe (10.0 mmol), $^nBuB(OH)_2$ (15.0 mmol), base (20.0 mmol), solvent (30 mL), **2i** (0.5 mol% Pd), 100 °C, 18 h. Conversion to 4-BuC_6H_4OMe determined by GC (hexadecane internal standard). NMP is *N*-methylpyrollidone.

It is apparent that the performance of catalysts based on the diisopropylphosphinite ligand **4q** is highly dependent on the palladium source, with only the preformed palladacyclic complex **2i** showing good activity. By contrast both of the more π-acidic ligands $PPh_2(OAr)$, **4h**, and $P(OAr)_3$ (Ar = C_6H_3-2,4-$^tBu_2$) are tolerant of palladium source, with no real change in activity observed with varying catalyst precursors. It appears that as the π-acidity of the $PR_2(OAr)$ ligands increases (R = ^{i}Pr < Ph < OAr) then so does the activity. However steric factors can be equally important as demonstrated by the good activity observed with PCy_3 since this ligand is far less π-acidic than the others used but is sterically hindered.

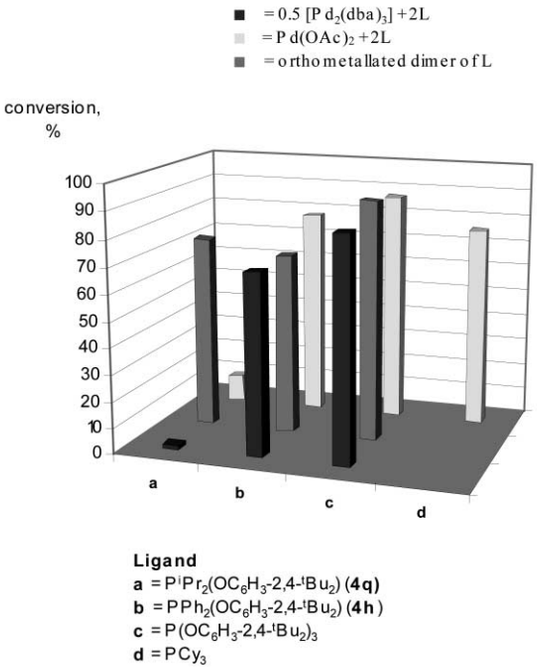


Fig. 4 Suzuki coupling of *n*-butylboronic acid with 4-bromoanisole. Conditions: 4-BrC_6H_4OMe (10.0 mmol), ^{n}BuB$(OH)_2$ (15.0 mmol), K_3PO_4 (20.0 mmol), 1,4-dioxane (30 mL), catalyst (0.5 mol% Pd), 100 °C, 18 h. Conversion to 4-BuC_6H_4OMe determined by GC (hexadecane internal standard).

Phosphine adducts of phosphinite palladacycles as catalysts for the Suzuki coupling of aryl chlorides

While the phosphinite palladacycles **2** show outstanding activity in the Suzuki coupling of aryl bromides, their performance with aryl chlorides is somewhat less impressive. We recently found that the tricyclohexylphosphine adducts of palladacycles, **3**, show, to the best of our knowledge, the highest activity yet reported in such reactions.[5] The application of PCy_3 adducts of the phosphinite-containing palladacycles was examined. Fig. 5 shows the time-dependent study of the reaction between the electronically deactivated substrate 4-chloroanisole and phenylboronic acid, catalysed by PCy_3 adducts formed *in situ*. For comparison purposes the data for the catalysts formed *in situ* from **1a** and **1c** and PCy_3 are included. In all cases an induction time of up to about 1 hour is observed. As can be seen both of the adducts formed from the complexes **2a** and **2i** show excellent activity – the TON obtained by 24 hours is nearly 30,000 in both cases – but their overall performance is not as great as the adducts formed from the phosphite complexes **1a** and **1c**. Interestingly it appears that the catalysts that show highest turn-over frequencies (TOF = TON/t) show the lowest overall conversion. The rate-determining step is almost certainly oxidative-addition of the aryl chloride as evidenced by the fact that the more electron-rich the palladium centre formed *in situ* from the palladacycles, the higher the initial rates of catalysis. Therefore the catalyst resting state is a zerovalent species, assuming a Pd(0)/Pd(II) cycle is operative (*vide infra*).[18] The greater the π-acidity of the co-ligand, the greater the longevity of the catalyst, due to increased stability of the zerovalent resting state. Therefore, it seems that the overall performance of the catalyst is not governed by an increase in the rate of catalysis, but rather by a hugely enhanced catalyst lifetime. By contrast, under identical conditions, the PCy_3-containing amine-based palladacyclic catalyst **12**, shows a lifetime of only ≈ 30 minutes and a total conversion of 4%.[5a]

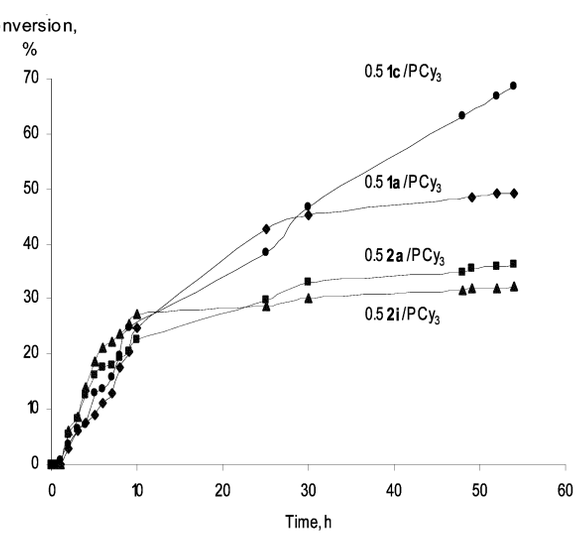
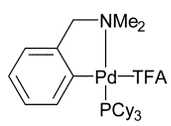


Fig. 5 Suzuki coupling of 4-chloroanisole with phenylboronic acid. Conditions: 4-ClC_6H_4Me (10.0 mmol), PhB$(OH)_2$ (15.0 mmol), Cs_2CO_3 (20.0 mmol), catalyst (0.001 mol% Pd), 1,4-dioxane (30 mL) hexadecane (internal standard, 0.204 mmol). Conversion to 4-methoxybiphenyl determined by GC.



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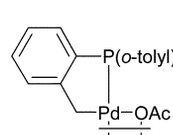
The possible role of orthometallation in the formation of active catalyst

It is apparent from the data above that phosphinite palladacycles are outstanding catalysts for the Suzuki coupling of aryl bromide substrates, while tricyclohexylphosphine adducts are excellent for aryl chloride coupling reactions. There has recently been considerable discussion on the subject of whether coupling reactions catalysed by palladacycles follow a 'classical' Pd(0)/Pd(II) pathway or rather whether the Pd–C bond is maintained and a Pd(II)/Pd(IV) pathway is operative.[18] In general the weight of evidence is pointing towards a classical Pd(0)/Pd(II) manifold, with active, zerovalent catalysts formed *in situ* either thermally or by a reductive process in which the metallated aryl group reacts with one of the coupling partners.[3,18]

In order to establish whether catalysts of the type **2** are likely to form Pd(0) or Pd(II) active catalysts, we investigated the reactions of complex **2e** with components of the Suzuki reaction. No reaction was observed between **2e** and 4-bromoacetophenone in toluene at reflux temperature. By contrast when **2e** was reacted with phenylboronic acid (4 molar equivalents/Pd) in the presence of K_2CO_3 (5 molar equivalents/Pd) in toluene at reflux temperature the reaction mixture rapidly turned black – within seconds of reaching about 50 °C. After 24 hours at reflux temperature the mixture was filtered to remove the inorganic solids and the resultant solution was analysed by GC/MS. This showed a peak corresponding to the ligand $PPh_2(OC_6H_4$-2-Ph), **4i**. Hydrolysis of the reaction mixture followed by GC/MS analysis indicated the presence of 2-phenylphenol. A plausible mechanism of decomposition which results in the liberation of the ligand **4i** and palladium metal is shown in Scheme 5. Similar ring-opening processes have been observed in the formation of active catalysts for the Suzuki reaction based on imine and amine palladacycles and for the formation of an active Stille coupling catalyst from the palladacycle **13**.[15,19,20] Far from being stable, it appears that palladacyclic Pd–C bonds are highly



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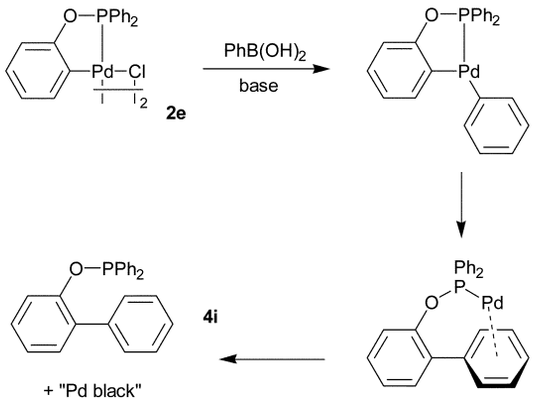
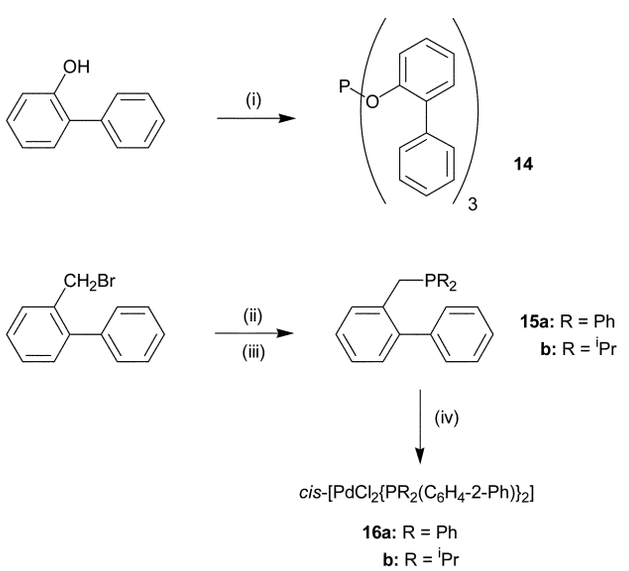


Scheme 5

reactive under catalytic conditions. We have recently exploited this reactivity in the rhodium catalysed, intermolecular ortho-arylation of phenols.[21]

The putative activation process outlined in Scheme 5 yields a low-coordinate palladium(0) species which contains a new 2-arylated phosphinite ligand. It is possible that the 2-aryl group helps stabilise the palladium centre by a π-interaction. Such stabilisation has previously been suggested by Buchwald as being an important feature in the high activity associated with palladium complexes of the ligands **6**.[22] Even if there is no specific stabilisation by π-coordination of the secondary aryl ring, the increase in size compared with the parent phosphinite may be anticipated to be beneficial in the Suzuki reaction. For this reason we undertook a comparison of phosphinite-, phosphite- and phosphine-containing catalyst systems with ECH_2-(C_6H_4-2-Ph) (E = O, CH_2) substituents. The syntheses of the phosphite ligand $P(OC_6H_4\text{-}2\text{-}Ph)_3$, **14**, and the phosphines $PR_2(CH_2C_6H_4\text{-}2\text{-}Ph)$, **15** (**a:** R = Ph, **b**: R = ^{i}Pr) are outlined in Scheme 6, as is the synthesis of the palladium dichloride adducts of the phosphines, the complexes **16**.



Scheme 6 Conditions: $\frac{1}{3}$ PCl_3, NEt_3, toluene, Δ, 18 h. (ii) Mg, Et_2O, 0 °C to r.t., 2 h. (iii) $ClPR_2$, 0 °C to r.t., 18 h. (iv) $[PdCl_2(NCMe)_2]$, CH_2Cl_2, r.t., 30 min.

The Suzuki reaction chosen for study was again the coupling of the deactivated aryl bromide 4-bromoanisole with phenylboronic acid. The catalysts studied were the preformed $[PdCl_2(L)_2]$ complexes and catalysts formed *in situ* from $[Pd(dba)_2]$ and two equivalents of the appropriate ligands. The results of the study are summarised in Fig. 6. In general it can be seen that the 2-phenylated ligands show much higher activity than their

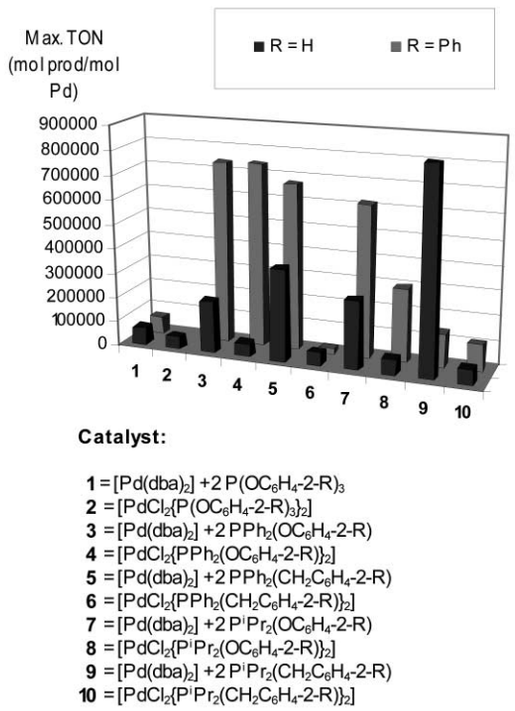


Fig. 6 Suzuki coupling of $PhB(OH)_2$ with $4\text{-}BrC_6H_4OMe$ with a variety of catalyst precursors and ligands. Conditions are the same as those used in Table 2 for aryl bromides.

unsubstituted counterparts. A major exception is seen with the catalyst formed *in situ* from $[Pd(dba)_2]$ and the phosphine $P^iPr_2(CH_2C_6H_5)$, **10b**, which shows by far the highest activity under these conditions, while the catalysts formed *in situ* from the 2-phenylated analogue $P^iPr_2(CH_2C_6H_4\text{-}2\text{-}Ph)$, **13b**, does not perform particularly well. At present we are unable to explain this exception. Another general trend that can be observed is that the catalysts formed *in situ* from $[Pd(dba)_2]$ and two equivalents of the ligands (Fig. 6, odd catalyst nos.) tend to show higher activity than the preformed catalysts of the form $[PdCl_2(L)_2]$ containing the same ligands.

Conclusions

Palladacycles based on orthopalladated phosphinite ligands are extremely active catalysts for the Suzuki coupling of aryl bromides; these catalysts can also be used successfully for the Suzuki coupling of alkyl boronic acids. While these catalysts are not particularly useful for the coupling of aryl chloride substrates, their tricyclohexylphosphine adducts, formed *in situ*, show very high activity. The high TONs obtained in the coupling of aryl chlorides appears to be as a result of high catalyst longevity, brought about by the stabilisation of the Pd(0) resting state by the π-acidic phosphinite ligands. This, coupled with the ease of synthesis of both the ligands and complexes from relatively inexpensive, commercially available precursors makes palladacyclic phosphinite complexes one of the foremost catalysts of choice for the Suzuki reaction.

Experimental

General

All reactions and manipulations of air-sensitive materials were carried out under nitrogen either in a glove-box or using standard Schlenk techniques. Solvents were dried and freshly distilled prior to use. All other chemicals were used as received. The ligands **4h**,**l** and **4q**,[8] the complexes **5a**, $[PdCl_2(NCMe)_2]$,[23] $[PdCl_2(NCPh)_2]$[24] and $[Pd(dba)_2]$[25] were prepared according to literature methods. GC analyses were performed on a Varian

3800 GC fitted with a 25 m CP Sil 5CB column and data were recorded on a Star workstation.

Syntheses

General method for the synthesis of $PPh_2(OAr)$ ligands. In a Schlenk tube under an atmosphere of nitrogen were placed the appropriate dried (toluene azeotrope) phenol, (34 mmol) chlorodiphenylphosphine (6.0 mL, 33.4 mmol), toluene (50 mL) and triethylamine (7.0 mL, 50.0 mmol). The resultant mixture was then heated at reflux temperature overnight, allowed to cool to room temperature and the precipitated $Et_3N^+HCl^-$ removed by filtration through a pad of Celite. The precipitate was washed with toluene (2 × 10 mL) and the combined organic fractions were then evaporated to dryness *in vacuo* yielding the phosphinite ligands which were not purified further.

$PPh_2(OPh)$, ***4a***. White solid, 97% yield. Found: C, 77.8; H, 5.3. Calc. for $C_{18}H_{15}OP$: C, 77.69; H, 5.41%. NMR ($CDCl_3$): δ_H (300 MHz) 7.09 (tt, 1H, $^3J_{HH}$ = 7.3 Hz, $^4J_{HH} \approx$ 2.0 Hz, OPh), 7.21 (d, 2H, $^3J_{HH}$ = 8.5 Hz, OPh), 7.32 (td, br, 2H, $^3J_{HH}$ = 8.0 Hz, $^4J_{HH}$ = 2.0 Hz, OPh), 7.46 (m, 6H, PPh_2), 7.68 (td, 4H, J_{HH} = 7.7 Hz, J_{HH} = 1.9 Hz, PPh_2) ppm. δ_P (121.5 MHz) 111.2 ppm.

$PPh_2(OC_6H_4$-4-Me), ***4b***. Pale yellow oil, 96% yield. NMR ($CDCl_3$): δ_H (300 MHz) 7.88 (m, br, 4H, PPh_2), 7.55 (m, 6H, PPh_2), 7.20 (s, br, 2H, OAr), 7.02 (dd, 2H, J = 2.0 Hz, J = 8.1 Hz, OAr), 2.52 (s, 3H, CH_3) ppm. δ_P (121.5 MHz) 111.8 ppm.

$PPh_2(OC_6H_4$-4-Me), ***4c***. Pale yellow oil, 97% yield. NMR ($CDCl_3$): δ_H (300 MHz) 7.75 (m, 4H, PPh_2), 7.50 (m, 6H, PPh_2), 7.20 (s, 4H, br, OAr), 2.68 (q, 2H, $^3J_{HH}$ = 7.0 Hz, CH_2CH_3), 1.35 (t, 3H, $^3J_{HH}$ = 7.0 Hz, CH_2CH_3) ppm. δ_P (121.5 MHz) 111.4 ppm.

$PPh_2(OC_6H_4$-4-^{t}Bu), ***4d***. White solid, 99% yield. NMR ($CDCl_3$): δ_H (300 MHz) 7.62 (m, 4H, PPh_2), 7.4 (m, 6H, PPh_2), 7.30 (dd, 2H, $^3J_{HH}$ = 6.6 Hz, J = 2.0 Hz, OAr), 7.07 (dd, 2H, $^3J_{HH}$ = 6.9 Hz, $^5J_{HH}$ = 1.6 Hz, OAr), 1.34 (s, 9H, ^{t}Bu) ppm. δ_P (121.5 MHz) 110.9 ppm.

$PPh_2(OC_6H_4$-2-Me), ***4e***. Pale yellow oil, 95% yield. NMR ($CDCl_3$): δ_H (300 MHz) 7.90 (m, 4H, PPh_2), 7.55 (m, 6H, PPh_2), 7.35 (d, 1H, $^3J_{HH}$ = 7.5 Hz, OAr), 7.32 (d, 1H, $^3J_{HH}$ = 7.4 Hz), 7.15 (m, 2H, OAr), 2.55 (s, 3H, CH_3) ppm. δ_P (121.5 MHz) 110.1 ppm.

$PPh_2(OC_6H_3$-2,4-Me_2), ***4f***. Pale yellow oil, 95% yield. NMR ($CDCl_3$): δ_H (300 MHz) 7.78 (m, 4H, $^3J_{HH}$ = 7.7 Hz, J_{HH} = 1.7 Hz, PPh_2), 7.50 (m, 6H, PPh_2), 7.11 (s, br, 1H, OAr), 7.05 (apparent d, br, 2H, $^3J_{HH} \approx$ 8.0 Hz, OAr), 2.41 (s, br, 6H, CH_3) ppm. δ_P (121.5 MHz) 110.3 ppm.

$PPh_2(OC_6H_4$-2-^{t}Bu), ***4g***. White solid, 98.5% yield. NMR ($CDCl_3$): δ_H (300 MHz) 7.65 (m, 4H, PPh_2), 7.43 (m, 6H, PPh_2), 7.35 (dd, 1H, $^3J_{HH}$ = 8.0 Hz, J_{HH} = 1.0 Hz, OAr), 7.15 (d, 1H, $^3J_{HH}$ = 6.4 Hz, OAr), 7.13 (d, 1H, $^3J_{HH}$ = 6.3 Hz, OAr), 7.00 (td, 1H, $^3J_{HH}$ = 6.4 Hz, J_{HH} = 1.0 Hz, OAr), 1.39 (s, 9H, ^{t}Bu) ppm. δ_P (121.5 MHz) 108.6 ppm.

$PPh_2(OC_6H_4$-2-Ph), ***4i***. Yellow oil, 96%. Found: C, 81.4; H, 5.5. Calc. for $C_{24}H_{19}OP$: C, 81.34; H, 5.40%. NMR ($CDCl_3$): δ_H 7.55 (m, 6H), 7.18 (m, 5H), 7.35 (m, 8H) ppm. δ_P (121.5 MHz) 113.3 ppm.

General method for the synthesis of $P^iPr_2(OAr)$ ligands. In a Schlenk tube under an atmosphere of nitrogen were placed the appropriate dried (toluene azeotrope) phenol, (32 mmol) chlorodiisopropylphosphine (5.0 mL, 31.4 mmol), toluene (80 mL) and triethylamine (5 mL, 35.9 mmol). The resultant mixture was then heated at reflux temperature overnight, allowed to cool to room temperature and petroleum ether (50 mL) added. The precipitated $Et_3N^+HCl^-$ was removed by filtration through a pad of Celite and washed with petroleum ether (3 × 10 mL) and the combined organic fractions were then evaporated to dryness *in vacuo* yielding the phosphinite ligands which were not purified further.

$P^iPr_2(OPh)$, ***4j***. Pale yellow oil, 89%. Found: C, 69.1; H, 9.1. Calc. for $C_{12}H_{19}OP$: C, 68.55; H, 9.10%. NMR ($CDCl_3$): δ_H (300 MHz) 7.38 (dd, 2H, $^3J_{HH}$ = 7.2 Hz, $^4J_{HH}$ = 2.0 Hz, OPh), 7.25 (m, 1H, H4), 7.05 (m, br, 2H, OPh), 2.08 (apparent dh, 2H, $^3J_{HH}$ = 7.0 Hz, $^2J_{PH}$ = 2.5 Hz, $CH(CH_3)_2$), 1.35 (dd, 6H, $^3J_{HH}$ = 7.0 Hz, $^3J_{PH}$ = 10.7 Hz, $CH(CH_3)_2$), 1.30 (dd, 6H, $^3J_{HH}$ = 7.2 Hz, $^3J_{PH}$ = 15.9 Hz, $CH(CH_3)_2$) ppm. δ_P (121.5 MHz) 149.0 ppm.

$P^iPr_2(OC_6H_4$-4-Me), ***4k***. Yellow oil, 92%. NMR ($CDCl_3$): δ_H (300 MHz) 7.11 (dd, 2H, $^3J_{HH}$ = 7.0 Hz, $J \approx$ 0.5 Hz, OAr), 7.06 (dd, 2H, $^3J_{HH}$ = 7.3 Hz, J = 1.6 Hz, OAr), 2.37 (s, 3H, CH_3), 1.95 (apparent dh, 2H, $^3J_{HH}$ = 7.0 Hz, $^2J_{PH}$ = 2.4 Hz, $CH(CH_3)_2$), 1.25 (dd, 6H, $^3J_{HH}$ = 6.9 Hz, $^3J_{PH}$ = 10.7 Hz, $CH(CH_3)_2$), 1.17 (dd, 6H, $^3J_{HH}$ = 7.2 Hz, $^3J_{PH}$ = 15.9 Hz, $CH(CH_3)_2$) ppm. δ_P (121.5 MHz) 149.6 ppm.

$P^iPr_2(OC_6H_4$-4-^{t}Bu), ***4m***. Pale yellow oil, 94%. NMR ($CDCl_3$): δ_H (300 MHz) 7.38 (dd, 2H, $^3J_{HH}$ = 7.0 Hz, J = 2.2 Hz, OAr), 7.15 (dd, 2H, $^3J_{HH}$ = 6.7 Hz, J = 1.7 Hz, OAr), 2.04 (apparent dh, 2H, $^3J_{HH}$ = 7.0 Hz, $^2J_{PH}$ = 2.3 Hz, $CH(CH_3)_2$), 1.43 (s, 9H, ^{t}Bu), 1.31 (dd, 6H, $^3J_{HH}$ = 7.0 Hz, $^3J_{PH}$ = 10.7 Hz, $CH(CH_3)_2$), 1.25 (dd, 6H, $^3J_{HH}$ = 7.3 Hz, $^3J_{PH}$ = 15.9 Hz, $CH(CH_3)_2$) ppm. δ_P (121.5 MHz) 148.9 ppm.

$P^iPr_2(OC_6H_4$-2-Me), ***4n***. Yellow oil, 94%. NMR ($CDCl_3$): δ_H (300 MHz) 7.42 (dd, 1H, $^3J_{HH}$ = 6.0 Hz, J_{HH} = 1.6 Hz, OAr), 7.20 (m, 2H, OAr), 6.95 (apparent t, 1H, $^3J_{HH}$ = 6.0 Hz, OAr), 2.35 (s, 3H, CH_3), 2.05 (apparent dh, 2H, $^3J_{HH}$ = 7.0 Hz, $^2J_{PH}$ = 2.6 Hz $CH(CH_3)_2$), 1.27 (dd, 6H, $^3J_{HH}$ = 7.2 Hz, $^3J_{PH}$ = 10.4 Hz, $CH(CH_3)_2$), 1.15 (dd, 6H, $^3J_{HH}$ = 7.3 Hz, $^3J_{PH}$ = 15.7 Hz, $CH(CH_3)_2$) ppm. δ_P (121.5 MHz) 144.5 ppm.

$P^iPr_2(OC_6H_4$-2,4-Me_2), ***4o***. Yellow oil, 95%. NMR ($CDCl_3$): δ_H (300 MHz) 7.37 (dd, 1H, J = 3.5, J = 1.3 Hz, H3, OAr), 7.07 (d, br, 2H, $^3J_{HH}$ = 7.4 Hz, OAr), 2.44 (s, 3H, CH_3), 2.42 (s, 3H, CH_3), 2.12 (apparent dh, 2H, $^3J_{HH}$ = 7.1 Hz, $^2J_{PH}$ = 2.8 Hz, $CH(CH_3)_2$), 1.38 (dd, 6H, $^3J_{HH}$ = 6.9 Hz, $^3J_{PH}$ = 10.7 Hz, $CH(CH_3)_2$), 1.30 (dd, 6H, $^3J_{HH}$ = 7.2 Hz, $^3J_{PH}$ = 15.6 Hz, $CH(CH_3)_2$) ppm. δ_P (121.5 MHz) 144.3 ppm.

$P^iPr_2(OC_6H_4$-2-^{t}Bu), ***4p***. Pale yellow oil, 96%. NMR ($CDCl_3$): δ_H (300 MHz) 7.46 (m, 1H, $^3J_{HH}$ = 7.3, J = 1.7 Hz, OAr), 7.31 (m, 2H, OAr), 7.04 (m, 1H, OAr), 2.25 (apparent dh, 2H, $^3J_{HH}$ = 7.1 Hz, $^2J_{PH}$ = 3.1 Hz, $CH(CH_3)_2$), 1.70 (dd, 6H, $^3J_{HH}$ = 7.0 Hz, $^3J_{PH}$ = 11.2 Hz, $CH(CH_3)_2$), 1.62 (dd, 6H, $^3J_{HH}$ = 5.9 Hz, $^3J_{PH}$ = 14.0 Hz, $CH(CH_3)_2$), 1.53 (s, 9H, ^{t}Bu) ppm. δ_P (121.5 MHz) 138.5 ppm.

$P^iPr_2(OC_6H_4$-2-Ph), ***4r***. Yellow-orange oil, 82%. Found: C, 75.9; H, 8.15. Calc. for $C_{18}H_{23}OP$: C, 75.50; H, 8.10%. NMR ($CDCl_3$): δ_H 7.67 (m, 2H), 7.54 (m, 3H), 7.45 (m, 3H), 7.16 (m, 1H), 1.95 (apparent dh, 2H, $^3J_{HH}$ = 6.5 Hz,$^2J_{PH}$ = 2.1 Hz, $CH(CH_3)_2$), 1.24 (dd, 6H, $^3J_{HH}$ = 7.0 Hz, $^3J_{PH}$ = 9.6 Hz, $CH(CH_3)_2$), 1.15 (dd, 6H, $^3J_{HH}$ = 7.0 Hz, $^3J_{PH}$ = 15.4 Hz, $CH(CH_3)_2$) ppm. δ_P (121.5 MHz) 151.5 ppm.

General method for the synthesis of the orthopalladated complexes of the ligands $PPh_2(OAr)$ with groups larger than methyl in the 2- or 4-position(s). In a Schlenk tube under an atmosphere of nitrogen, were placed palladium dichloride (0.25 g, 1.40 mmol) the appropriate phosphinite ligand (1.40 mmol) and toluene (30 mL). The reaction mixture was heated at reflux temperature overnight, allowed to cool and then the solvent was removed *in vacuo*. The residue was extracted with dichloromethane (30 mL) and filtered through a pad of Celite. Ethanol was added to induce precipitation of the product which was collected by filtration and recrystallised from CH_2Cl_2/EtOH.

[{Pd(μ-Cl){κ²-P,C-$PPh_2(OC_6H_2$-2,4-^{t}Bu$_2$)}}$_2$], ***2a***. Yellow solid, 82% yield. Found: C, 59.2; H, 5.9. Calc. for $C_{52}H_{60}O_2P_2Pd_2Cl_2$: C, 59.10; H, 5.90%. Two isomers obtained in a 1.15 : 1 ratio. NMR ($CDCl_3$): *both isomers* (integrations approximate) δ_H (300 MHz) 7.95 (m, 8H, PPh_2), 7.85 (m, 8H, PPh_2), 7.605 (s, br, 2H, OAr), 7.595 (s, br, 2H, OAr), 7.49 (m, 12H, PPh_2), 7.40 (m, 12H, PPh_2), 7.06 (s, br, 4H, OAr), 1.39 (s, br, 36H, ^{t}Bu), 1.35

(s, 18H, ^{t}Bu); 1.28 (s, 18H, ^{t}Bu) ppm. δ_P (121.5 MHz) 155.2 (major isomer), 154.7 (minor isomer) ppm.

[{Pd(μ-Cl){κ²-P,C-PPh$_2$(OC$_6$H$_3$-4-^{t}Bu)}}$_2$], ***2b***. Yellow solid, 43% yield. Found: C, 55.9; H, 5.01. Calc. for $C_{44}H_{44}O_2P_2Pd_2Cl_2$: C, 55.60; H, 4.67%. Two isomers obtained in a 1.25 : 1 ratio. NMR ($CDCl_3$): *major isomer* δ_H (300 MHz) 7.62 (d, br, 2H, $^3J_{HH}$ = 8.2 Hz, OAr), 7.53 (m, 8H, PPh$_2$), 7.49 (m, 12H, PPh$_2$), 7.06 (s, br, 4H, OAr), 1.33 (s, 18H, ^{t}Bu) ppm. δ_P (121.5 MHz) 153.9 ppm. *Minor isomer* δ_H 7.96 (m, 8H, PPh$_2$), 7.84 (m, 12H, PPh$_2$), 7.61 (d, 2H, $^3J_{HH}$ = 10.0 Hz, OAr), 6.81 (s, br, 4H, OAr), 1.27 (s, 18H, ^{t}Bu) ppm. δ_P 154.4 ppm.

[{Pd(μ-Cl){κ²-P,C-PPh$_2$(OC$_6$H$_3$-2-^{t}Bu)}}$_2$], ***2c***. Yellow solid, 49%. Found: C, 55.6; H, 4.7. Calc. for $C_{44}H_{44}O_2P_2Pd_2Cl_2$: C, 55.60; H, 4.67%. Two isomers obtained in a 1.6 : 1 ratio. NMR ($CDCl_3$): *major isomer* δ_H (300 MHz) 7.73 (apparent t, br, 2H, $^3J_{HH}$ = 5.0 Hz, OAr), 7.53 (m, 12H, PPh$_2$), 7.48 (m, 8H, PPh$_2$), 7.07 (s, br, 2H, OAr), 7.05 (s, br, 2H, OAr), 1.33 (s, br, 18H, ^{t}Bu) ppm. δ_P (121.5 MHz) 155.7 ppm. *Minor isomer* δ_H 7.95 (m, 12H, PPh$_2$), 7.86 (m, 8H, PPh$_2$), 6.98 (apparent t, 2H, $^3J_{HH}$ = 5.0 Hz, OAr), 6.83 (m, 4H, OAr), 1.49 (s, br, 18H, ^{t}Bu) ppm. δ_P 155.0 ppm.

[{Pd(μ-Cl){κ²-P,C-PPh$_2$(OC$_6$H$_3$-4-Et)}}$_2$], ***2d***. Yellow solid, 86%. Found: C, 54.0; H, 4.05.Calc. for $C_{40}H_{36}O_2P_2Pd_2Cl_2$: C, 53.71; H, 4.06%. Two isomers obtained in a 1.36 : 1 ratio. NMR ($CDCl_3$): *major isomer* δ_H (300 MHz) 7.64 (s, br, 2H, OAr), 7.54 (m, 8H, PPh$_2$), 7.47 (m, 12H, PPh$_2$), 6.98 (s, br, 4H, OAr), 2.52 (q, 4H, $^3J_{HH} \approx$ 7.0 Hz, C*H*$_2$CH$_3$), 1.17 (t, br, 6H, $^3J_{HH} \approx$ 7.0 Hz, CH$_2$C*H*$_3$) ppm. δ_P (121.5 MHz) 154.1 ppm. *Minor isomer* δ_H 7.94 (m, 12H, PPh$_2$), 7.86 (m, 8H, Ph ring), 7.40 (m, 2H, OAr), 6.82 (s, 2H, OAr), 6.80 (s, 2H, OAr), 2.61 (q, 4H, $^3J_{HH}$ = 6.9 Hz, C*H*$_2$CH$_3$), 1.18 (t, 6H, $^3J_{HH}$ = 6.9 Hz, CH$_2$C*H*$_3$) ppm. δ_P 153.4 ppm.

General method for the synthesis of the orthopalladated complexes of the ligands PPh$_2$(OAr) with only methyl or smaller groups in the 2- or 4-position(s). In a Schlenk tube under an atmosphere of nitrogen were placed bis(benzonitrile)dichloropalladium (0.50 g, 1.30 mmol), the appropriate phosphinite ligand (1.4 mmol) and THF (30 mL). The reaction mixture was heated at reflux temperature overnight, allowed to cool and then the solvent was removed *in vacuo*. The residue was extracted with dichloromethane (30 mL) and filtered through a pad of Celite. The filtrate was concentrated under reduced pressure and ethanol was added to induce precipitation. The product was collected by filtration and recrystallised from CH_2Cl_2/EtOH.

[{Pd(μ-Cl){κ²-P,C-PPh$_2$(OC$_6$H$_4$)}}$_2$], ***2e***. Cream solid, 80%. Found: C, 51.85; H, 3.2. Calc. for $C_{36}H_{28}O_2P_2Pd_2Cl_2$: C, 51.58; H, 3.37%. Two isomers obtained in a 1.13 : 1 ratio. NMR ($CDCl_3$): *both isomers* (integrations approximate) δ_H (300 MHz) 7.89 (m, 8H, PPh$_2$), 7.66 (m, 12H, PPh$_2$), 7.47 (t, 2H,$^3J_{HH}$ = 7.0 Hz, OPh), 7.45 (m, 8H, PPh$_2$), 7.32 (m, 12H, PPh$_2$), 7.23 (t, 2H, $^3J_{HH}$ = 7.0 Hz OPh); 7.10 (m, 4H, OPh), 6.93 (m, 4H, OPh), 6.85 (d, br, 4H, $^3J_{HH}$ = 6.0 Hz, OPh) ppm. δ_P (121.5 MHz) 157.5 (minor isomer), 154.8 (major isomer) ppm.

[{Pd(μ-Cl){κ²-P,C-PPh$_2$(OC$_6$H$_3$-2,4-Me$_2$)}}$_2$], ***2f***. Yellow solid, 67%. Found: C, 54.1; H, 4.5. Calc. for $C_{40}H_{36}O_2P_2Pd_2Cl_2$: C, 53.71; H, 4.06%. Two isomers obtained in a 1.27 : 1 ratio. NMR ($CDCl_3$): *major isomer* δ_H (300 MHz) 7.53 (m, 8H, PPh$_2$), 7.48 (m, 12H, PPh$_2$), 6.69 (s, br, 4H, OAr), 2.23 (s, br, 12H, CH$_3$) ppm. δ_P (121.5 MHz) 151.9 ppm. *Minor isomer* δ_H 7.93 (m, 12H, PPh$_2$), 7.84 (m, 8H, PPh$_2$), 7.20 (m, 4H, OAr), 2.15 (s, br, 12H, CH$_3$) ppm. δ_P 151.1 ppm.

[{Pd(μ-Cl){κ²-P,C-PPh$_2$(OC$_6$H$_3$-4-Me)}}$_2$], ***2g***. Yellow solid, 77%. Two isomers obtained in a 1.34 : 1 ratio. NMR ($CDCl_3$): *major isomer* δ_H (300 MHz) 7.74 (m, 2H, OAr), 7.55 (m, 8H, PPh$_2$), 7.42 (m, 12H, PPh$_2$), 6.87 (m, 4H, OAr), 2.3 (s, br, 6H, CH$_3$) ppm. δ_P (121.5 MHz) 154.1 ppm. *Minor isomer* δ_H 7.94 (m, 8H, PPh$_2$), 7.85 (m, 12H, PPh$_2$), 7.35 (m, 2H, OAr), 6.80 (s, br, 2H, OAr), 6.78 (2, br 2H, OAr), 2.15 (s, 6H, CH$_3$) ppm. δ_P 153.3 ppm.

[{Pd(μ-Cl){κ²-P,C-PPh$_2$(OC$_6$H$_3$-2-Me)}}$_2$], ***2h***. Yellow solid, 78.5%. Two isomers obtained in a 1.38 : 1 ratio. NMR ($CDCl_3$): *major isomer* δ_H (300 MHz) 7.56 (s, br, 2H, OAr), 7.55 (m, 8H, PPh$_2$), 7.47 (m, 12H, PPh$_2$), 6.88 (s, 2H, OAr), 6.86 (s, 2H, OAr), 2.29 (s, br, 6H, CH$_3$) ppm. δ_P (121.5 MHz) 152.6 ppm. *Minor isomer* δ_H 7.93 (m, 12H, PPh$_2$), 7.86 (m, 8H, PPh$_2$), 6.73 (m, 2H, OAr), 6.70 (m, 4H, OAr), 2.62 (s, 6H, CH$_3$) ppm. δ_P 151.9 (s) ppm.

Synthesis of [{Pd(μ-Cl){κ²-*P*,*C*-P^{i}Pr$_2$(OC$_6$H$_2$-2,4-^{t}Bu$_2$)}}$_2$], 2i. In a Schlenk tube under an atmosphere of nitrogen were placed, palladium dichloride (0.25 g, 1.40 mmol), the phosphinite ligand **4p** (0.451 g, 1.40 mmol) and 1,4-dioxane (30 mL). The reaction mixture was heated at reflux temperature overnight, allowed to cool and then the solvent was removed *in vacuo*. The residue was extracted in dichloromethane (30 mL), filtered through a pad of Celite and ethanol was then added to induce precipitation of the product. The crude product was recrystallised from CH_2Cl_2/EtOH to give **2i** as an orange solid, 0.31 g, 47% yield. Found: C, 52.1; H, 7.2. Calc. for $C_{40}H_{68}O_2P_2Pd_2Cl_2$: C, 51.85; H, 7.40%. Two isomers obtained in a 1.2 : 1 ratio. NMR ($CDCl_3$): *major isomer* δ_H (300 MHz) 7.03 (s, br, 4H, OAr), 2.50 (apparent dh, 4H, $^3J_{HH}$ = 7.4 Hz, $^2J_{PH}$ = 2.1 Hz, C*H*(CH$_3$)$_3$), 1.35 (dd, 12H, $^3J_{HH}$ = 7.3 Hz, $^3J_{PH}$ = 9.5 Hz, CH(C*H*$_3$)$_2$), 1.32 (s, 18H, ^{t}Bu), 1.28 (s, 18H, ^{t}Bu), 1.25 (dd, 12H, $^3J_{HH}$ = 7.3 Hz, $^3J_{PH}$ = 12.3 Hz, CH(C*H*$_3$)$_2$) ppm. δ_P (121.5 MHz) 203.4 ppm. *Minor isomer* δ_H 7.67 (s, br, 2H, OAr), 7.53 (d, br, 2H, OAr), 2.40 (apparent dh, 4H, $^3J_{HH}$ = 7.3 Hz, $^2J_{PH}$ = 1.9 Hz, C*H*(CH$_3$)$_3$), 1.53 (s, 18H, ^{t}Bu), 1.42 (dd, 6H, $^3J_{HH}$ = 7.3 Hz, $^3J_{PH}$ = 9.6 Hz, CH(C*H*$_3$)$_2$), 1.39 (dd, 12H, $^3J_{HH}$ = 7.3 Hz, $^3J_{PH}$ = 13.1 Hz, CH(C*H*$_3$)$_2$), 1.40 (s, 18H, ^{t}Bu) ppm. δ_P 202.7 ppm.

General method for the synthesis of the complexes [PdCl$_2$(4)$_2$], 5. A solution of [PdCl$_2$(NCMe)$_2$] (0.50 g, 1.93 mmol) and the appropriate phosphinite ligand (3.85 mmol) in dichloromethane (30 mL) was stirred at room temperature for 4 hours. The solvent was then removed under reduced pressure and the solid residue recrystallised from dichloromethane/hexane.

cis/trans-[PdCl$_2${P^{i}Pr$_2$(OPh)}$_2$], ***5c***. Cream solid, 61%. Found: C, 48.9; H, 6.1. Calc. for $C_{24}H_{38}Cl_2O_2P_2Pd$: C, 48.22; H, 6.41%. Two isomers obtained in a 1.1 : 1 ratio. NMR ($CDCl_3$): *major isomer* δ_H (300 MHz) 7.44 (dd, 2H, $^3J_{HH}$ = 7.0 Hz, $J \approx$ 1.0 Hz, OPh), 7.00 (dd, 4H, $^3J_{HH}$ = 7.5 Hz, J_{HH} = 1.5 Hz, OPh), 6.76 (d, br, 4H, $^3J_{HH}$ = 7.5 Hz, OPh), 2.43 (apparent dh, 4H, $^3J_{HH}$ = 7.1 Hz, $^2J_{PH}$ = 2.1 Hz, C*H*(CH$_3$)$_3$), 1.36 (dd, 12H, $^3J_{HH}$ = 6.9 Hz, $^3J_{PH}$ = 7.3 Hz, CH(C*H*$_3$)$_2$, major isomer), 1.30 (dd, 12H, $^3J_{HH}$ = 6.9 Hz, $^3J_{PH}$ = 7.3 Hz, CH(C*H*$_3$)$_2$). δ_P (121.5 MHz) 163.8 ppm. *Minor isomer* δ_H 7.71 (dd, 2H, $^3J_{HH}$ = 6 Hz, $J \approx$ 2.0 Hz, OPh), 7.37 (dd, 4H, $^3J_{HH}$ = 7.5 Hz, $J \approx$ 1.4 Hz, OPh), 6.85 (d, br, 4H, $^3J_{HH}$ = 7.5 Hz, OPh), 2.83 (apparent dh, 4H, $^3J_{HH}$ = 7.0 Hz, $^2J_{PH}$ = 2.1 Hz, C*H*(CH$_3$)$_3$), 1.46 (dd, 12H, $^3J_{HH}$ = 7.0 Hz, $^3J_{PH}$ = 7.2 Hz, CH(C*H*$_3$)$_2$), 1.41 (dd, 12H, $^3J_{HH}$ = 7.0 Hz, $^3J_{PH}$ = 7.2 Hz, CH(C*H*$_3$)$_2$) ppm. δ_P 164.0 ppm. IR (KBr) ν(Pd–Cl) 362, 310, 335 cm^{-1}.

[PdCl$_2${P^{i}Pr$_2$(OC$_6$H$_3$-2,4-^{t}Bu$_2$)}$_2$], ***5d***. Colourless solid, 78%. Found: C, 59.1; H, 8.3. Calc. for $C_{40}H_{70}Cl_2O_2P_2Pd$: C, 58.43; H, 8.58%. Two isomers obtained in a 1.34 : 1 ratio. NMR ($CDCl_3$): *major isomer* δ_H (300 MHz) 8.16 (dd, 2H, $^3J_{HH}$ = 8.0 Hz, J = 2.0 Hz, OAr), 7.19 (d, 2H, J = 2.0 Hz, OAr), 6.99 (d, 2H, $^3J_{HH}$ = 8.0 Hz, OAr), 2.77 (apparent dh, 4H, $^3J_{HH}$ = 7.0 Hz, $^2J_{PH}$ = 2.0 Hz, C*H*(CH$_3$)$_3$), 1.61 (dd, 12H, $^3J_{HH}$ = 7.2 Hz, $^3J_{PH}$ = 10.1 Hz, CH(C*H*$_3$)$_2$), 1.57 (dd, 12H, $^3J_{HH}$ = 7.2 Hz, $^3J_{PH}$ = 9.9 Hz, CH(C*H*$_3$)$_2$), 1.35 (s, br, 18H, ^{t}Bu), 1.27 (s, br, 18H, ^{t}Bu major isomer) ppm. δ_P (121.5 MHz) 143.8 ppm. *Minor isomer* δ_H 8.08 (d, 2H, $^3J_{HH}$ = 8.0 Hz, OAr), 7.30 (dd, 2H, $^3J_{HH}$ = 8.0 Hz, J = 2.0 Hz, OAr), 6.92 (s, br, 2H, OAr), 2.42 (apparent dh, 4H, $^3J_{HH}$ = 7.0 Hz, $^2J_{PH}$ = 2.0 Hz, C*H*(CH$_3$)$_3$, minor isomer), 1.46 (dd, 12H, $^3J_{HH}$ = 7.3 Hz, $^3J_{PH}$ = 10.2 Hz, CH(C*H*$_3$)$_2$), 1.42 (dd,

br, 12H, $^3J_{HH}$ = 7.3 Hz, $^3J_{PH}$ = 9.8 Hz, CH(CH_3)$_2$), 1.24 (s, br, 18H, ^{t}Bu), 1.14 (s, br, 18H, ^{t}Bu) ppm. δ_P 142.6 (minor isomer) ppm. IR (KBr) ν(Pd–Cl) 372, 342, 320 cm^{-1}.

*trans-[PdCl$_2${PPh$_2$(OC$_6$H$_4$-2-Ph)}$_2$], **5e**.* Orange solid, 18%. Found: C 65.1; H, 4.3. Calc. for $C_{48}H_{38}O_2P_2PdCl_2$: C, 65.92; H, 4.01%. NMR ($CDCl_3$): δ_H (300 MHz) 7.58 (m, 12H) 7.40 (m, 16H), 7.21 (m, 10H) ppm. δ_P (121.5 MHz) 108.5 ppm. IR (KBr) ν(Pd–Cl) 374 cm^{-1}.

Synthesis of *trans*-[PdCl$_2${P^{i}Pr$_2$(OC$_6$H$_3$-2-Ph)}$_2$], 5f. A mixture of [PdCl$_2$(NCMe)$_2$] (0.25 g, 0.965 mmol) and 2-phenylphenyl diisopropylphosphinite, **4r**, (0.55 g, 1.93 mmol) in toluene (40 mL) was heated at reflux temperature overnight. The solution was allowed to cool and filtered through a pad of Celite which was washed with dichloromethane. The volatiles were removed from the combined solution under reduced pressure and the residue recrystallised from CH_2Cl_2/EtOH to give the product as a yellow solid, 23%. Found: C, 58.1; H, 5.9. Calc. for $C_{36}H_{46}O_2P_2PdCl_2$: C, 57.65; H, 6.18%. NMR ($CDCl_3$): δ_H (300 MHz) 7.72 (m, 2H, Ph), 7.64 (m, 4H, Ph), 7.52 (m, 2H, Ph), 7.19 (m, 1H, Ph), 1.96 (apparent dh, 4H, $^3J_{HH}$ = 6.5 Hz, $^2J_{PH}$ = 2.1 Hz, CH(CH$_3$)$_3$), 1.20 (dd, 12H, $^3J_{HH}$ = 5.9 Hz, $^3J_{PH}$ = 10.2 Hz, CH(CH_3)$_2$), 1.11 (dd, 12H, $^3J_{HH}$ = 5.9 Hz, $^3J_{PH}$ = 14.8 Hz, CH(CH_3)$_2$) ppm. δ_P (121.5 MHz) 142.1 ppm. IR (KBr) ν(Pd–Cl) 369 cm^{-1}.

Synthesis of P^{i}Pr$_2$(CH$_2$Ph), 10b. Magnesium shavings (0.30 g, 12.30 mmol) were activated by stirring with a seed crystal of iodine, under an atmosphere of nitrogen overnight. Et$_2$O (50 mL) was added, the mixture was cooled to 0 °C and benzyl chloride (1.65 g, 13.10 mmol) was added dropwise to the cooled solution. The resultant solution was allowed to warm to room temperature and stirred for a total of 2 hours. The supernatant liquid was removed from the unreacted Mg with a filter cannula, cooled to 0 °C and chlorodiisopropylphosphine (2.0 mL, 12.5 mmol) was added dropwise. The mixture was left to stir at room temperature overnight and then filtered through a pad of Celite which was washed with diethyl ether. The combined solution was evaporated to dryness under reduced pressure to give the product as a pale yellow solid, 2.31 g, 89%. Found: C, 75.3; H, 10.0. Calc. for $C_{13}H_{20}P$: C, 74.97; H, 10.16%. NMR ($CDCl_3$): δ_H (300 MHz) 7.22 (d, 2H, $^3J_{HH}$ = 6.8 Hz, Ph), 7.18 (dd, 2H, $^3J_{HH}$ = 5.0 Hz, $^3J_{HH}$ = 6.8 Hz, Ph), 7.04 (t, 1H, $^3J_{HH}$ = 5.0 Hz, Ph), 4.43 (s, 2H, CH_2), 1.61 (apparent dh, 2H, $^3J_{HH}$ = 7.0 Hz, $^2J_{PH}$ = 2.1 Hz, CH(CH$_3$)$_2$), 1.02 (dd, 6H, $^3J_{HH}$ = 6.8 Hz, $^3J_{PH}$ = 9.8 Hz, CH(CH_3)$_2$), 0.94 (dd, 6H, $^3J_{HH}$ = 6.8 Hz, $^3J_{PH}$ = 14.2 Hz, CH(CH_3)$_2$) ppm. δ_P (121.5 MHz) −7.9 ppm.

Synthesis of P(OC$_6$H$_4$-2-Ph)$_3$, 14. To a solution of dried (toluene azetrope) 2-phenylphenol (29.26 g, 0.17 mol) in toluene (80 mL) was added PCl_3 (5.0 mL, 57.0 mmol) dropwise and then triethylamine (25.0 mL, 0.18 mol) dropwise. The mixture was heated at reflux temperature overnight, allowed to cool and then filtered through a pad of Celite to remove the precipitated triethylamine hydrochloride. The solvent was removed under reduced pressure to yield the crude product as a brown oil which was then purified by column chromatography (silica, hexane/dichloromethane 1 : 1). The title product was obtained as a white solid, 12.45 g, 42.5%. NMR ($CDCl_3$): δ_H (300 MHz) 7.40 (m, 12H), 7.35 (m, 3H), 7.18 (m, 6H), 6.92 (m, 6H) ppm. δ_P (121.5 MHz) 130.5 ppm.

General method for the synthesis of the phosphines PR$_2$-(CH$_2$C$_6$H$_4$-2-Ph), 15. Magnesium shavings (0.49 g, 0.02 mol) were activated by stirring with a seed crystal of iodine, under an atmosphere of nitrogen overnight. Dry degassed diethyl ether (50 mL) was added, the mixture was cooled to 0 °C and 2-phenylbenzylbromide (5.00 g, 0.02 mol) was added dropwise to the cooled solution. The resultant solution was allowed to warm to room temperature and stirred for a total of 2 hours. The supernatant liquid was removed from the unreacted Mg with a filter cannula, cooled to 0 °C and the appropriate chlorophosphine (0.02 mol) was added dropwise. The mixture was left to stir at room temperature overnight and then filtered through a pad of Celite which was washed with diethyl ether. The combined solution was evaporated to dryness under reduced pressure to give the phosphines which were not purified further.

*PPh$_2$(CH$_2$C$_6$H$_4$-2-Ph), **15a**.* Cream solid, 74.1%. Found: C, 84.9, H; 5.8. Calc. for $C_{25}H_{21}P$: C, 85.20; H, 6.00%. NMR ($CDCl_3$): δ_H (300 MHz) 7.36 (m, 4H), 7.26 (complex m, br, 15H), 3.45 (m, 2H, CH_2) ppm. δ_P (121.5 MHz) −8.11 ppm.

*P^{i}Pr$_2$(CH$_2$C$_6$H$_4$-2-Ph), **15b**.* White solid, 81%. Found: C, 79.9; H, 8.6. Calc. for $C_{19}H_{25}P$: C, 80.25; H, 8.86%. NMR ($CDCl_3$): δ_H (300 MHz) 7.34 (m, 4H, Ph), 7.21 (m, 5H, Ph), 3.40 (m, 2H, CH_2), 2.20 (apparent dh, 2H, $^3J_{HH}$ = 6.0 Hz, $^2J_{PH}$ = 2.0 Hz, CH(CH$_3$)$_2$), 1.21 (dd, 6H, $^3J_{HH}$ = 6.7 Hz, $^3J_{PH}$ = 9.2 Hz, CH(CH_3)$_2$), 1.15 (dd, 6H, $^3J_{HH}$ = 6.7 Hz, $^3J_{PH}$ = 13.4 Hz, CH(CH_3)$_2$) ppm. δ_P (121.5 MHz) −6.54 ppm.

General method for the synthesis of the phosphine complexes [PdCl$_2${PR$_2$(CH$_2$C$_6$H$_4$-2-R)}$_2$], 11 (R = H) and 16 (R = Ph). A solution of [PdCl$_2$(NCMe)$_2$] (0.50 g, 1.93 mmol) and the appropriate phosphine, (3.85 mmol) in dichloromethane (10 mL) was stirred at room temperature for 30 minutes after which time, MeOH (10 mL) was added and the solution concentrated *in vacuo* to induce precipitation of the product which was then recrystallised from CH_2Cl_2/MeOH.

*cis-[PdCl$_2${PPh$_2$(CH$_2$Ph)}$_2$], **11a**.* Yellow solid, 61%. Found: C, 61.9, H; 4.2. Calc. for $C_{38}H_{34}P_2PdCl_2$: C, 62.53; H, 4.69%. NMR ($CDCl_3$): δ_H (300 MHz) 7.58 (m, br, 6H), 7.44 (m, br, 6H), 7.28 (m, 4H), 7.10 (m, 8H), 7.02 (m, 2H), 6.92 (m, 4H), 3.97 (m, 4H, CH_2) ppm. δ_P (121.5 MHz) 29.6 ppm. IR (KBr) ν(Pd–Cl) 302, 330 cm^{-1}.

*cis-[PdCl$_2${P^{i}Pr$_2$(CH$_2$Ph)}$_2$], **11b**.* Cream solid, 45%. Found: C, 53.2; H, 7.0. Calc. for $C_{26}H_{42}P_2PdCl_2$: C, 52.58; H, 7.13. NMR ($CDCl_3$): δ_H (300 MHz) 7.55 (d, br, 4H, $^3J_{HH}$ = 7.0 Hz, Ph), 7.38 (m, br, 6H, Ph), 4.28 (m, 4H, CH_2), 2.32 (apparent dh, 4H, $^3J_{HH}$ = 6.0 Hz, $^2J_{PH}$ = 2.1 Hz, CH(CH$_3$)$_3$), 1.25 (dd, br, 12H, $^3J_{HH}$ = 6.5 Hz, $^3J_{PH}$ = 9.9 Hz, CH(CH_3)$_2$), 1.20 (dd, br, 12H, $^3J_{HH}$ = 6.5 Hz, $^3J_{PH}$ = 14.5 Hz, CH(CH_3)$_2$) ppm. δ_P (121.5 MHz) 38.9 ppm. IR (KBr) ν(Pd–Cl) 301, 325 cm^{-1}.

*cis-[PdCl$_2${PPh$_2$(CH$_2$C$_6$H$_4$-2-Ph)}$_2$], **16a**.* Orange solid, 69%. Found: C, 68.6; H, 4.2. Calc. for $C_{50}H_{42}P_2PdCl_2$: C, 68.08; H, 4.80%. NMR ($CDCl_3$): δ_H (300 MHz) 8.47 (dd, 2H, $^5J_{HH}$ = 2.0 Hz, $^3J_{HH} \approx$ 7.0 Hz), 7.42 (m, 14H), 7.20 (m,12H), 7.08 (d, br, 4H, $^3J_{HH} \approx$ 7.0 Hz), 6.80 (d, br, 2H, J = 2.0 Hz), 6.55 (m, 4H), 4.13 (m, 4H, CH_2) ppm. δ_P (121.5 MHz) 31.0 ppm. IR (KBr) ν(Pd–Cl) 374 cm^{-1}.

*cis-[PdCl$_2${P^{i}Pr$_2$(CH$_2$C$_6$H$_4$-2-Ph)}$_2$], **16b**.* Yellow solid, 40%. Found: C, 61.85; H, 6.1. Calc. for $C_{38}H_{56}P_2PdCl_2$: C, 61.17; H, 6.75%. NMR ($CDCl_3$): δ_H (300 MHz) 7.42 (m, br, 8H) 7.31 (m, br, 10H), 3.65 (m, 4H, CH_2) 2.25 (apparent dh, 4H, $^3J_{HH}$ = 6.5 Hz, $^2J_{PH}$ = 2.2 Hz, CH(CH$_3$)$_3$), 1.24 (dd, 12H, $^3J_{HH}$ = 6.5 Hz, $^3J_{PH}$ = 9.5 Hz, CH(CH_3)$_3$), 1.15 (dd, 12H, $^3J_{HH}$ = 6.5 Hz, $^3J_{PH}$ = 13.5 Hz, CH(CH_3)$_3$) ppm. δ_P (121.5 MHz) 41 ppm. IR (KBr) ν(Pd–Cl) 378 cm^{-1}.

Catalysis

Suzuki coupling of aryl bromides with phenylboronic acid (Table 2, Fig. 2, Fig. 6). In a three-necked flask under an atmosphere of nitrogen were placed the appropriate aryl bromide (10.0 mmol), phenylboronic acid (1.83 g, 15.0 mmol), K_2CO_3 (2.76 g, 20.0 mmol) and toluene (30 mL total, including catalyst/added ligand solution). The correct amount of catalyst/added ligand was added as a toluene solution made up by multiple volumetric dilutions of a stock solution. The mixture was then heated at reflux temperature for 18 h, cooled in an ice

bath, quenched with aqueous HCl (2 M, 100 mL), extracted with dichloromethane (3 × 100 mL), dried ($MgSO_4$) and evaporated to dryness. Hexadecane (0.068 M in CH_2Cl_2, 3.00 mL) and dichloromethane (5–7 mL, to ensure complete dissolution) were added. The conversion to coupled product was then determined by GC analysis.

Suzuki coupling of aryl chlorides with phenylboronic acid (Table 2). As above but using DMA (*N*,*N*-dimethylacetamide) as solvent and Cs_2CO_3 as base. The reaction temperature was 110 °C.

Suzuki coupling of 4-bromoanisole with *n*-butylboronic acid (Fig. 4). In a three-necked flask under an atmosphere of nitrogen were placed 4-bromoanisole (1.87 g, 10.0 mmol), butylboronic acid (1.56 g, 15.0 mmol), K_3PO_4 (4.24 g, 20.0 mmol) and 1,4-dioxane (30 mL total, including catalyst/added ligand solution). The catalyst was added as a dioxane solution made up by multiple volumetric dilutions of a stock solution. The mixture was heated at reflux temperature for 18 h, cooled in an ice bath, quenched with aqueous HCl (2 M, 100 mL) and extracted with CH_2Cl_2 (3 × 100 mL). The combined extracts were dried ($MgSO_4$) and then the solvent was removed on a rotary evaporator. Hexadecane (0.068 M in CH_2Cl_2, 3.00 mL) and dichloromethane (5–7 mL, to ensure complete dissolution) were added. The conversion to coupled product was then determined by GC analysis.

Time-dependant study on the coupling of phenylboronic acid with 4-chloroanisole (Fig. 5). In a two-necked flask under an atmosphere of nitrogen were placed 4-chloroanisole (1.42 g, 10.0 mmol), phenylboronic acid (1.83 g, 15.0 mmol), Cs_2CO_3 (6.56 g, 20,0 mmol), hexadecane (0.068 M in 1,4-dioxane, 3 mL 0.204 mmol, internal standard), and 1,4-dioxane (26 mL). The mixture was then heated to 100 °C and the catalyst mixture was added as 1,4-dioxane (1.00 mL) solution made up to the correct concentration by multiple volumetric dilutions of a stock solution. The temperature was maintained at 100 °C for 120 min and 0.2 mL aliquots were taken at regular intervals. These samples were quenched in aqueous HCl (2 M, 0.5 mL), the mixture extracted with toluene (3 × 1 mL), the combined organic extracts dried ($MgSO_4$) and then the conversion to coupled product was determined by GC.

X-Ray structure determination of complex 2i

Suitable crystals were selected and data collected on a Bruker Nonius KappaCCD Area Detector at the window of a Bruker Nonius FR591 rotating anode ($\lambda_{Mo\text{-}K\alpha}$ = 0.71073 Å) driven by COLLECT[26] and DENZO[27] software at 120 K. Structures were determined in SHELXS-97[28] and refined using SHELXL-97.[29] Crystal data: $C_{21}H_{36}Cl_3OPPd$, M = 548.22, monoclinic, a = 10.63170(10), b = 22.1407(3), c = 11.3297(2) Å, β = 112.61°, U = 2461.91(6) Å^3, T = 120(2) K, space group $P2_1/c$ (no. 14), Z = 4, μ(Mo-K_α) = 1.154 mm^{-1}, 15633 reflections measured, 4331 unique (R_{int} = 0.056) which were used in all calculations. Final R_1 = 0.0283, wR_2 = 0.0690 [$F^2 > 2\sigma(F^2)$], R_1 = 0.0336, wR_2 = 0.0715 (all data).

CCDC reference number 207369.

See http://www.rsc.org/suppdata/dt/b3/b303657j/ for crystallographic data in CIF or other electronic format.

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