# NOVEL LEAD(IV) REAGENTS FOR CARBON-CARBON BOND FORMATION

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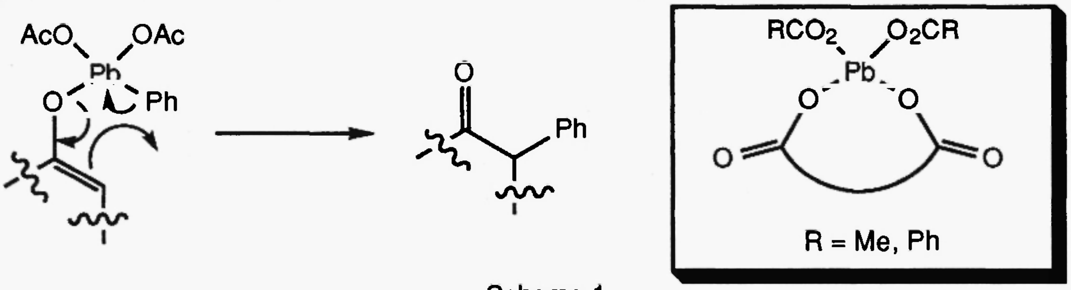
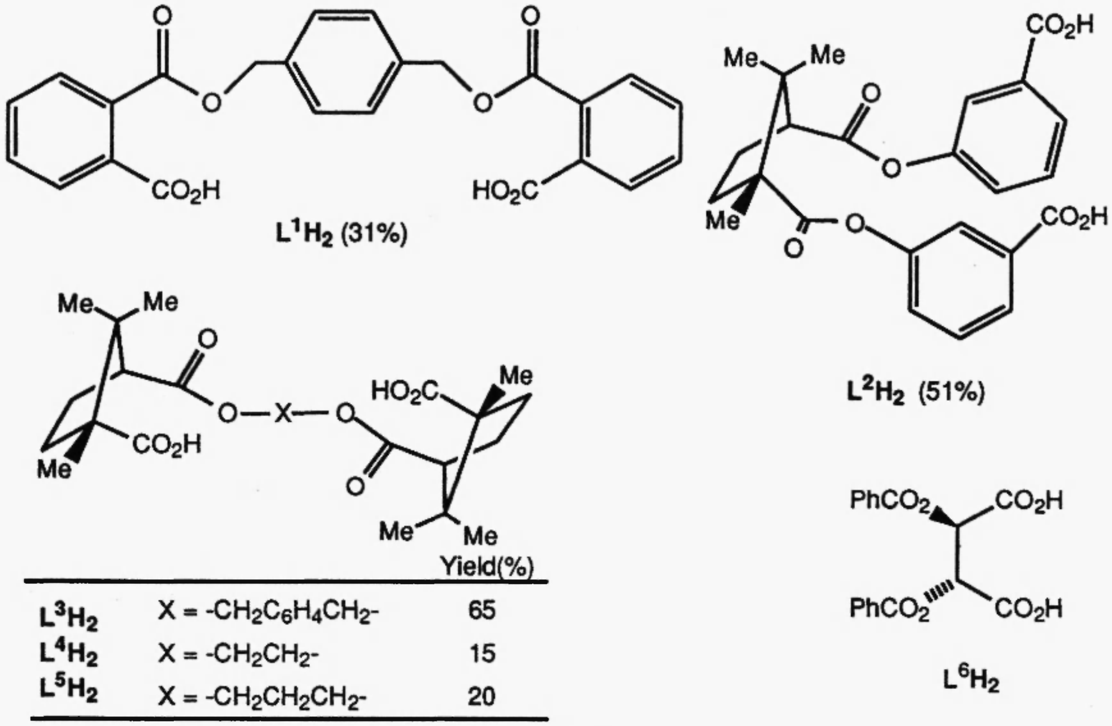
**Abstract:** The isolation and characterisation of a range of lead(IV) complexes, prepared from achiral and chiral dicarboxylic acids, is described. These compounds have been found to be stable amorphous solids, but upon reaction with phenylboronic acid and a variety of β-dicarbonyl substrates with mercury(II) catalysis, carbon-carbon bond formation can be readily achieved.

The application of transition metal catalysts for the formation of new carbon-carbon bonds has been extensively developed, and the Stille[1,2] and Suzuki[3] coupling reactions, mediated by palladium, are powerful synthetic procedures of considerable significance. These reactions proceed via a catalytic cycle involving a sequence of oxidative addition/reductive elimination processes at palladium.[4] The application of high oxidation state lead[5, 6] and bismuth[7] for carbon-carbon bond formation for a variety of reacting partners has also been developed. There is now considerable evidence that these latter processes occur by ligand coupling[8] at the lead[9] (Scheme 1) or bismuth centre,[10] and the possible intermediacy of radicals under the conditions of the reactions has been excluded.[11] We were interested in the possibility that replacement of acetate by alternative ligands might enhance the yields of the desired ligand coupling process, minimise competing side reactions (such as α-acetoxylation), and also offer the possibility of asymmetry transfer. That the efficiency of these couplings might be dependent on the identity of the lead(IV) ligands is suggested by a report that lead tetrabenzoate is superior to lead tetraacetate (LTA).[12] The choice of suitable alternative ligands is restricted by the highly oxidising nature of lead(IV),[13, 14] which could cause ligand degradation,[15] and the rapid ligand exchange which is known in lead(IV) carboxylate systems, even at low temperature.[16, 17] Our initial investigations have focused on achiral and chiral dicarboxylic acids which might have been expected to act as chelating ligands, thereby slowing ligand exchange, and in the case of chiral ligands, create an asymmetric environment around the metal cation. We report here the preparation of a range of mixed ligand lead(IV) dicarboxylates, and an examination of their reactivity in arylation reactions (Scheme 1).



Scheme 1

The dicarboxylic acids $L^1H_2$, $L^3H_2$, $L^4H_2$ and $L^5H_2$ (Scheme 2) were conveniently prepared by treating molten phthalic or (+)-(1R,3S)-camphoric anhydrides with diols of different chain lengths (benzenedimethanol, ethanediol and propanediol); although yields were not always high, the convenience and simplicity of the procedure enabled significant quantities to be prepared. Ligand $L^2H_2$ was obtained directly from camphoric acid by coupling of the acid chloride with t-butyl *m*-hydroxybenzoate, followed by trifluoroacetic acid deprotection. Because of the known propensity of carboxylates to act as bidentate chelates for lead(IV),[18] spacer arms were chosen to give the diacids sufficient flexibility to facilitate monomeric complex formation. Commercially available (-)-(2R,3R)-dibenzoyl tartaric acid ($L^6H_2$, Scheme 2) was also used as a dicarboxylic acid ligand. Complexation, by treating these dicarboxylates with LTA in toluene followed by removal of the solvent using a previously reported method,[19] was straightforward, and gave the corresponding lead(IV) complexes as isolable and characterisable yellow solids, although they were not stable to recrystallisation. By using the appropriate stoichiometry of ligands, either lead(IV) bis(dicarboxylates), or (dicarboxylate)diacetates, dibenzoates or ditoluates could be readily obtained (see Table). The hydrolytic stability of the bis(dicarboxylates) and dibenzoates was greater than the corresponding diacetates, although the solubilities of the latter complexes in chloroform were generally better. Evidence that these complexes were indeed Pb(IV) complexes was obtained from combustion analysis, $^1$H NMR spectra (which indicated that acetate had been removed and that ligand decomposition had not occurred) and from IR spectroscopy (which indicated the disappearance of the carboxylic acid carbonyl absorption). Additionally, $^{207}$Pb NMR spectroscopy indicated the presence of lead species, which were not LTA, within the characteristic lead(IV) chemical shift range (δ -1850 to -1890ppm).[19]



$L^1H_2$ (31%)

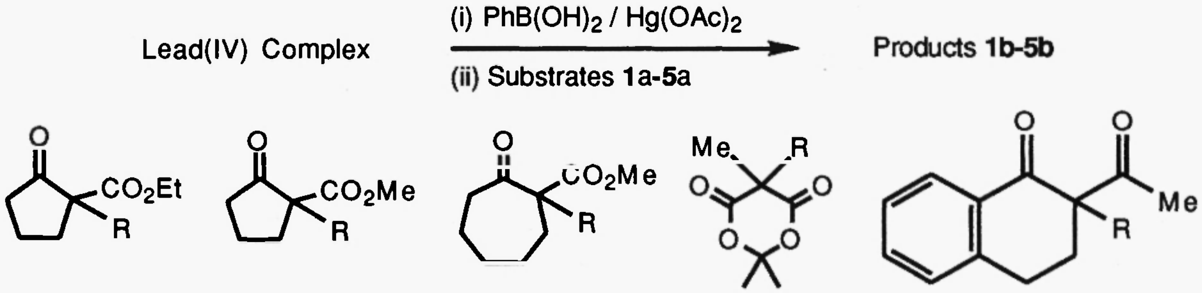
$L^2H_2$ (51%)

| | | Yield(%) |
|---|---|---|
| $L^3H_2$ | X = $-CH_2C_6H_4CH_2-$ | 65 |
| $L^4H_2$ | X = $-CH_2CH_2-$ | 15 |
| $L^5H_2$ | X = $-CH_2CH_2CH_2-$ | 20 |

$L^6H_2$

Scheme 2

Treatment of complexes Pb($L^1$)$_2$ and Pb($L^2$)$_2$ with allyltributylstannane gave no isolable products, but the dibenzoates Pb($L^1$)($O_2CPh$)$_2$, Pb($L^2$)($O_2CPh$)$_2$, and Pb($L^3$)($O_2CPh$)$_2$ reacted to give allyl benzoate as shown by $^1$H NMR spectroscopic examination of the crude reaction mixture, thereby indicating that the metal cation had not been rendered completely inert upon complexation. However, the reaction of some of the complexes with phenylboronic acid, in the presence of mercury(II) acetate, followed by a range of β-dicarbonyl substrates using the two-step procedure developed by Pinhey,[20] gave moderate to good isolated yields of the corresponding α-phenyl products **1b-5b** (Scheme 3 and Table).[21] The yields of these products using LTA are included for comparison. Thus, despite the greater relative stability of these lead(IV) complexes over LTA, their reaction under appropriate conditions to give carbon-carbon formation in comparable yields to the LTA system was nonetheless possible. However, extended reaction times did not give a significant increase in the observed yields. It is noteworthy that diacetate Pb($L^1$)(OAc)$_2$, although relatively unstable, gave a moderate yield (37%) of the corresponding phenylated product **2b**, if prepared and used immediately. In general, the products **1b-5b** could be readily obtained in pure form by careful column chromatography, although the better yields for product **4b** using a variety of lead(IV) complexes probably reflects its ease of isolation when compared to the other substrates.



**1a** R = H
**1b** R = Ph

**2a** R = H
**2b** R = Ph

**3a** R = H
**3b** R = Ph

**4a** R = H
**4b** R = Ph

**5a** R = H
**5b** R = Ph

Scheme 3

**Table** : Yields for Products **1b-5b** from Substrates **1a-5a** according to Scheme 3.

| Lead(IV) Complex | Yields of Products (%) | | | | |
|---|---|---|---|---|---|
| | 1 b | 2 b | 3 b | 4 b | 5 b |
| $Pb(OAc)_4$ | $67^b$ | 70 | 77 | 71 | 50 |
| $PbL^1(O_2CPh)_2$ | - | - | - | 52 | - |
| $PbL^2(O_2CPh)_2$ | - | 44 (0,-$^c$) | - | 62 | - |
| $PbL^3{}_2$ | 18 | 10 (12,4$^c$) | $8^b$ | 0 | - |
| $PbL^3(O_2CPh)_2$ | a | 21 (8,4$^c$) | 17 (6,8$^c$) | 52 | 8 |
| $PbL^3(OAc)_2$ | - | 37 (8, 1$^c$) | - | - | - |
| $PbL^4(O_2CPh)_2$ | - | 69 (10, 6$^c$) | - | - | - |
| $PbL^5(O_2CPh)_2$ | - | $57^d$ | - | - | - |
| $PbL^6(O_2CPh)_2$ | - | 71 (4, 4$^c$) | - | - | - |
| $PbL^6(O_2CAr)_2{}^e$ | - | 58 (4, 4$^c$) | - | - | - |

[a] Product shown to be present by GCMS analysis of the crude reaction mixture. [b] Yield estimated from the $^1H$ nmr spectrum of crude product. [c] Enantiomeric excess (by chiral shift $^1H$ NMR spectrosopy, by chiral GC). [d] $HgCl_2$ catalysed. [e] Ar = p-$MeC_6H_4$

In the case of chiral complexes derived from $L^2H_2$-$L^6H_2$, the generation of the α-phenyl products with chiral induction at the new quarternary centre might have been expected; examination of the products **2b,** prepared using these complexes, by both chiral shift $^1H$ NMR spectrosopy ($Eu(tfc)_3$ at 250 or 300MHz) and chiral GC (Chiraldex™ or Lipodex™ column) indicated that e.e. values in the region of 4-12% had been obtained (Table). These low values could reflect the distance of the stereogenic centres from the metal cation in the complexes, but another possibility is the presence of multiple lead(IV) species in solution (either monomeric or oligomeric), each possessing differing reactivity, and if the most reactive of these was an achiral species then poor overall transfer of chirality would be obtained. Such behaviour is well known in transition metal systems.[22] Evidence to support this latter postulate came from a careful examination of the $^{207}Pb$ NMR spectrum of the dibenzoate complex $Pb(L^3)(O_2CPh)_2$; at room temperature, the spectrum was observed to be broad, indicating the presence of a number of different lead(IV) species in solution. At 225K, the spectrum was resolved into a number of peaks, and the identity of some of the signals could be assigned by comparison to reference samples[17] and clearly indicated the presence of LTA, $Pb(O_2CPh)_4$, $Pb(OAc)(O_2CPh)_3$, $Pb(OAc)_2(O_2CPh)_2$, $Pb(OAc)_3(O_2CPh)$, and $PbL^3{}_2$. This situation is made even more complex by the addition of the catalyst mercury acetate, which adds acetate as potential ligands. The identity of the most reactive species for arylation in such mixtures is not clear, but will be of significance in any possible aymmetric induction. Thus, it appears that the dicarboxylic acid ligands are not sufficiently strongly chelating that they prevent ligand equilibration, and this is likely to be the cause of the poor asymmetry transfer in the case of the chiral ligands.

Thus, we have demonstrated that a range of lead(IV) complexes derived from dicarboxylic acids can be readily isolated as stable compounds, and that these complexes are useful for the creation of new carbon-carbon bonds. Further work to identify ligand systems which do not equilibrate so readily and give better asymmetric induction is underway, and will be reported in due course.

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21. All new compounds gave satisfactory spectroscopic and high resolution mass spectrometric or analytical data. Data for $PbL^6(O_2CC_6H_4Me)_2$ : yellow solid. m.p. 128-130°C; (Found C, 48.63; H, 3.19%. $C_{34}H_{26}O_{12}Pb$ requires C, 48.98; H, 3.14%.); $[\alpha]_D^{22}$ +20.5 (*c* 1.00 in $CHCl_3$); $\nu_{max}$ (Nujol/cm$^{-1}$) 1734 (s, C=O), 1604 (m), 1587 (m), 1413 (s), 1261 (s) and 1241 (s); $\delta_H$ (200MHz, $CDCl_3$) 2.38 (6H, s, $2xC\underline{H}_3$), 6.11 (2H, s, $2xC\underline{H}$), 7.05-7.49 (10H, m, Ar$\underline{H}$), 7.74 (4H, br, s, Ar$\underline{H}$) and 7.99 (4H, d, *J* = 7.5Hz, Ar$\underline{H}$); $\delta_C$ (50.3MHz, $CDCl_3$) 21.76 ($2x\underline{C}H_3$), 72.41 ($\underline{C}H$), 123.61, 128.50, 129.48, 130.27, 130.38, 132.12, 133.70 (Ar$\underline{C}$ and Ar$\underline{C}$H), 145.70 (Ar$\underline{C}CH_3$), 165.14 (Ph$\underline{C}$=O) and 174.85 ($\underline{C}$=O); $\delta_{Pb}$ (52.3MHz, $CDCl_3$, 223K) -1893.16, -1891.60 and -1888.87.
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