



Novel alkylation, lactonisation and cascade coupling processes mediated by lead tetracarboxylates: the importance of ligands

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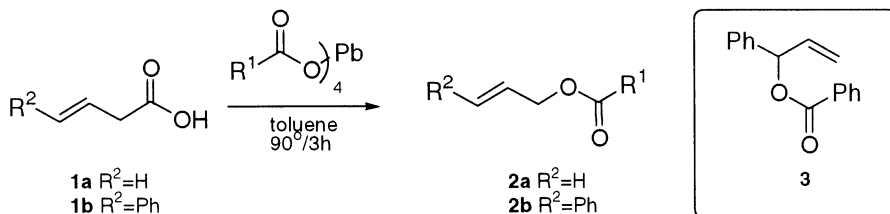
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Abstract—The reactions of lead(IV) tetracarboxylates with carboxylic acids containing unsaturated side chains is reported. At elevated temperature in toluene, facile decarboxylation or lactonisation processes are observed, depending on the length of the carboxylate side chain and in some cases further cascade coupling processes with added nucleophiles are possible. The efficiency of these processes depends on the structure of the carboxylate ligand and the mechanistic implications of these results are briefly discussed. © 2002 Elsevier Science Ltd. All rights reserved.

The use of lead tetraacetate (LTA) for a wide variety of oxidative processes^{1–4} and more recently for cross coupling reactions^{5,6} is well known. We have for some time been interested in the further development of the application of lead(IV) as a reagent in synthetic organic chemistry, and our attention has focussed on a detailed investigation of suitable carboxylate ligands for lead(IV), both for their stabilising effect on the metal cation⁷ as well as their solution exchange behaviour.⁸ We have, for example, shown that lead tetra-(thiophenecarboxylate) is a mild oxidant suitable for the oxidation of reactive alcohols to aldehydes.⁹ However, asymmetric induction of lead(IV)-mediated arylations in the presence of chiral ligands is very low,^{10,11} and this we have attributed to a facile ligand exchange in solution on the basis of NMR evidence. However, of the ligands we have hitherto examined, all have themselves proved to be unreactive to lead(IV).

In keeping with our desire to identify novel reaction processes mediated by lead(IV), we have recently examined carboxylic acid ligands which possess ω -unsaturated hydrocarbon side chains. The reactions of

lead(IV) with such compounds, such as oxidative decarboxylations, are well known and have been shown to proceed through a free radical chain mechanism especially if conducted in the presence of a copper(II) catalyst.^{12,4} However, the exact course of such lead(IV) mediated reactions critically depend on several factors, including the substrate structure, the solvent and the presence of additives (e.g. Cu(II) or halides), and the operation of heterolytic mechanisms has also been acknowledged.⁴ Another type of lead(IV)-mediated reaction, that of lactonisation, was originally reported by Alder and Schneider¹³ and later investigated by Criegee¹⁴ and Corey,¹⁵ although mechanistic details were not elaborated; more recently, a variant on this reaction involving lactonisations of δ -stannylcarboxylic acids has been described.¹⁶ However, the synthetic scope of many of these reactions has not been investigated in detail, and we report here some preliminary results that indicate that they may in fact be more useful for synthetically novel processes than has hitherto been appreciated; careful choice of ligands and reaction conditions, however, appear to be critical for success.



Scheme 1.

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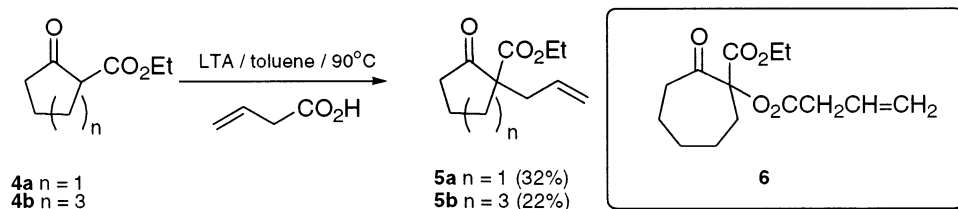
3-Butenoic acid **1a** was treated in toluene at 90°C for 3 h with a variety of lead(IV) tetracarboxylates (Scheme 1 and Table 1), themselves prepared by simple ligand metathesis of lead tetracetate using our reported procedure.⁷ Allyl esters **2a** were obtained in yields ranging from moderate to good (entries 1–10).^{17,18} Although the yields were best for simple carboxylates (acetate, benzoate and cinnamate, entries 1, 2 and 3), carboxylates with bulky *ortho*-substituents (dichloro and dimethoxybenzoate, entries 8 and 9) and 2-thienylcarboxylate were found to be almost as good, but other carboxylates generally gave poor yields. The utility of 2-thienylcarboxylate for other metal-mediated coupling processes has recently been reported.^{19,20} Toluene was found to be far

superior than THF or acetonitrile for this reaction, which can be formally considered to proceed with the loss of CO₂ and the generation of an allyl carbocation or radical equivalent. In the case of 4-phenyl-3-butenoic acid **1b**, reaction with lead tetrabenzoate under the standard conditions gave a mixture of the two possible products, **2b** (R¹=Ph) and **3**, in low overall yield (11 and 4%, respectively), although in this case the yields were not optimised. It is noteworthy that inclusion of β-dicarbonyl substrates **4a,b** in these reactions gave the allylated products **5a,b** (Scheme 2) in moderate yield, but in the case of the cycloheptanone derivative **4b**, the carboxylated product **6** was also isolated (8%). Similar acetoxylation processes with lead tetraacetate are well-known.²¹ Furthermore, dicarbonyl **7a** was efficiently converted to allyl product **7b** under these conditions in 59% yield.

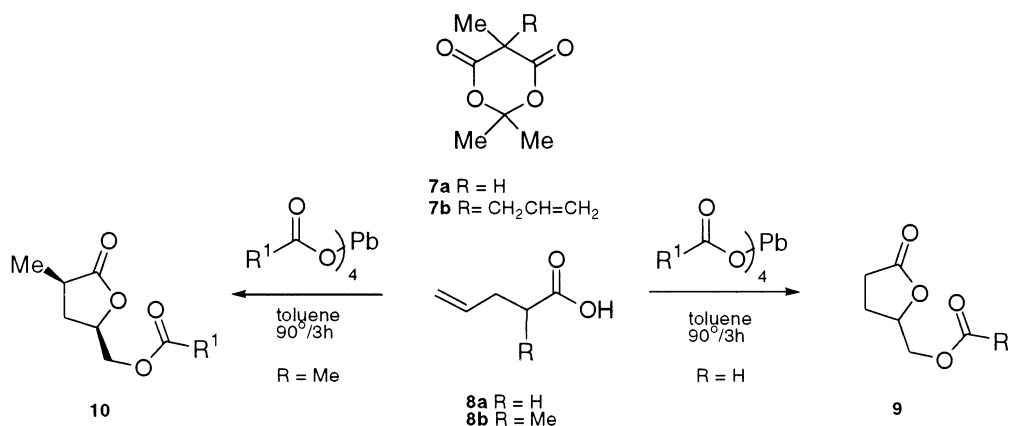
Table 1. Reaction of unsaturated carboxylic acids **1** and **8a** according to Schemes 1 and 3

Entry	R ¹	R ²	2 , Yield (%)	9 , Yield (%)
1	Me	H	68	85
2	Ph	H	75	45
3	PhC=CH	H	68	7
4	<i>p</i> -BrC ₆ H ₄	H	28	–
5	<i>p</i> -MeOC ₆ H ₄	H	41	39
6	3,4-(MeO) ₂ C ₆ H ₃	H	37	30
7	2,4-(MeO) ₂ C ₆ H ₃	H	22	48
8	2,6-(MeO) ₂ C ₆ H ₃	H	58	60
9	2,6-Cl ₂ C ₆ H ₃	H	56	22
10	2-Thienyl	H	53	84
11	Ph	Ph	11	–

In the case of the next higher homologue, 4-pentenoic acid **8a**, treatment with a variety of lead(IV) tetracarboxylates gave the lactones **9** again in variable yield (Scheme 3 and Table 1), but noteworthy are the yields of the acetate, 2,6-dimethoxybenzoate and 2-thienylcarboxylate (entries 1, 8 and 10). Although presumably decarboxylation is not favoured in this case, nonetheless the leaving group ability of lead(IV) induces a ring closure to give the observed lactone product. When this reaction was applied to the α-methyl analogue **8b**, the *cis*-lactone **10** was formed in 65% yield with complete stereoselectivity, whose structure was established by single-crystal X-ray analysis. However, in contrast to the reactions of acid **1a**, inclusion of β-dicarbonyl substrates **4a,b** in the reactions of acid **8a** did not result in the



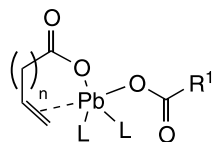
Scheme 2.



Scheme 3.

formation of any trapping adducts. Interestingly, the reaction of 4-pentenoic acid **8a** with lead tetraacetate in benzene has been previously reported, but lactone **9** ($R^1 = \text{Me}$) was not among the identified products.²²

Of some interest is the mechanism of this reaction; as indicated above, carbocation or radical intermediates are possibilities. The formation of many of the observed products (i.e. allylated compounds **2**, α -carboxyl compounds **6** and lactones **9** and **10**) could be considered, by analogy to literature precedent, to occur by a radical mechanism, but the formation of others is more problematic (e.g. **5a,b** and **7b**). When the reaction of lead tetrabenzoate with 3-butenic acid was conducted in the presence of radical inhibitors such as galvinoxyl or benzoquinone (0.1–0.2 equiv.), the product **2a** ($R^1 = \text{Ph}$) was still formed (40 and 27%, respectively), although these yields are lower than in the absence of the trapping agents (Table 1, entry 2). Similarly, reaction of 4-pentenoic acid with lead tetrabenzoate in the presence of galvinoxyl or benzoquinone (0.1–0.2 equiv.), gave lactone **9** ($R^1 = \text{Ph}$) in 67 and 29%, respectively. Evidence against the intermediacy of discrete carbocations or radicals came from reactions performed in the presence of 1,1-diphenylethene (1 equiv.); under these conditions, no products arising from trapping were observed, with the diphenylethene itself being in fact recovered and the expected products **2a** or **9** still being formed (yield of **2a** ($R^1 = (\text{MeO})_2\text{C}_6\text{H}_3$) 83%, recovery of alkene 66%; yield of **9** ($R^1 = (\text{MeO})_2\text{C}_6\text{H}_3$) 29%, 100% recovery of alkene). These results suggest that another mechanism may be operating, and all of the above results could be neatly accommodated by the intermediacy of a lead(IV) compound of type **11** which collapses in a one- or two-electron sense to give ligand coupling leading directly to the observed products; of interest is that the intermediacy of a lead species in these types of reaction was suggested nearly 35 years ago, but no structural details were given.²³ Ligand coupling for organolead(IV) carboxylates has been demonstrated by Pinhey to be a facile process,^{5,6} but the possibility of such a mechanism for the reactions of lead tetracarboxylates has hitherto not been considered. Unfortunately, attempts to observe a species such as **11** by ¹H or ²⁰⁷Pb NMR spectroscopy has been unsuccessful. The existence of such an intermediate could also account for the difference in coupling observed with β -dicarbonyl compounds depending on the chain length of the starting unsaturated acid; for **11** ($n = 1$), decarboxylation could lead to a π -allyl type lead(IV) species, but for **11** ($n = 2$), decarboxylation could create a significantly less stabilised σ -lead(IV) species, which might be expected to collapse to the observed products before further ligand exchange with the β -dicarbonyl compound is possible.



11 $n = 1,2$

Further investigations to validate these mechanistic ideas and demonstrate the synthetic applications of this reaction will be reported in due course.

Acknowledgements

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