

Transition metal-stabilised vinylketenes

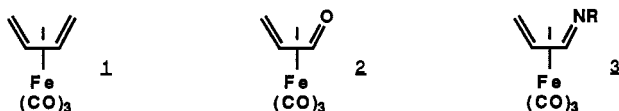
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Abstract - (Vinylketene)tricarbonyliron complexes are synthesised from readily-available (vinylketone)tricarbonyliron complexes. They react with isonitriles to give (vinylketenimine)tricarbonyliron complexes and with nucleophiles at C-1 to give β,γ -unsaturated carbonyl derivatives. In contrast (vinylketenimine)tricarbonyliron complexes react with nucleophiles at C-2 to give β,γ -unsaturated carbonyl derivatives containing an α quaternary centre. This approach has been used to generate homochiral quaternary centres.

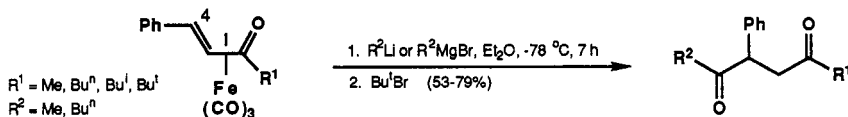
INTRODUCTION

Tricarbonyliron complexes of hydrocarbon dienes (**1**) have been studied intensively over the last thirty years. Their reactions with nucleophiles, electrophiles, carbenes, dienophiles *etc.* have all been investigated and documented (ref. 1-3). In contrast the reactivity of (oxadiene)tricarbonyliron complexes (**2**) and (azadiene)tricarbonyliron complexes (**3**) have been relatively neglected, and so four years ago we began a series of investigations designed to investigate whether or not these complexes and related complexes would undergo carbon-carbon bond forming reactions. In addition, we had a more distant goal which was to exploit the chirality of the complexes and eventually use them to form carbon-carbon bonds asymmetrically.



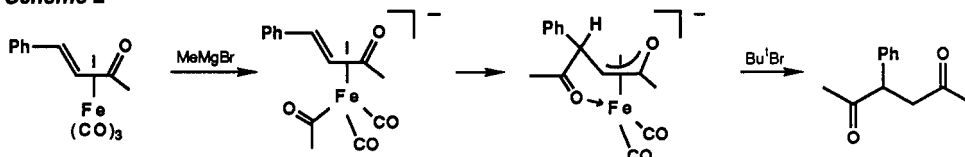
Our studies led to the discovery of several novel reactions including the following acylation processes. We found for example, that addition of hard nucleophiles such as alkyl-lithium and Grignard reagents to the (oxadiene)tricarbonyliron complexes gave 1,4-diketones in good yield (scheme 1) (ref. 4-5).

Scheme 1

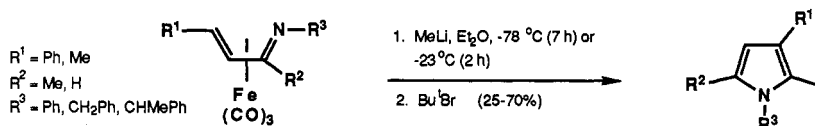


Thus nucleophilic attack occurs at a metal-carbonyl ligand to produce a metal-acyl anion. The acyl group then transfers to carbon 4 of the 1-oxadiene unit to generate an oxa-allyl intermediate in which electron deficiency at the iron centre may be circumvented by invoking co-ordination of the acyl oxygen atom. Protonation of this species gives rise to the product 1,4-diketone (scheme 2).

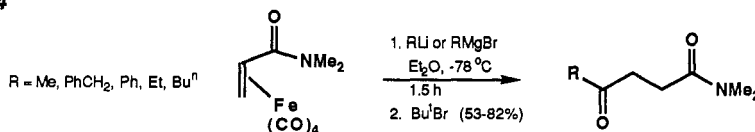
Scheme 2



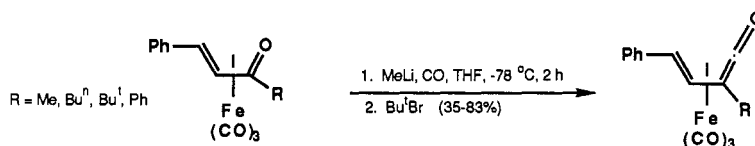
We also found that (azadiene)tricarbonyliron complexes underwent a related reaction *i.e.* they reacted with hard nucleophiles to give substituted pyrroles (scheme 3) (ref. 6-7). Again nucleophilic attack occurs at a metal-carbonyl ligand to give a metal-acyl anion. Transfer of the acyl group to carbon 4 of the azadiene in this case generates an aza-allyl intermediate which gives rise to the product pyrrole in a series of steps which presumably resemble the latter stages of the Paal-Knorr synthesis of pyrroles.

Scheme 3

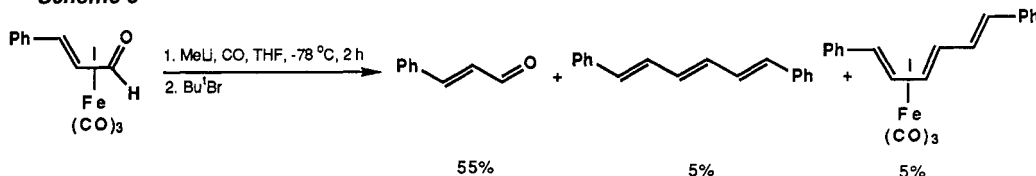
A third novel acylation reaction was discovered when it was observed that addition of hard nucleophiles to tetracarbonyliron complexes of vinyl amides gave 4-ketoamides (scheme 4) (ref. 8).

Scheme 4**SYNTHESIS OF (VINYLKETENE) TRICARBONYLIRON COMPLEXES**

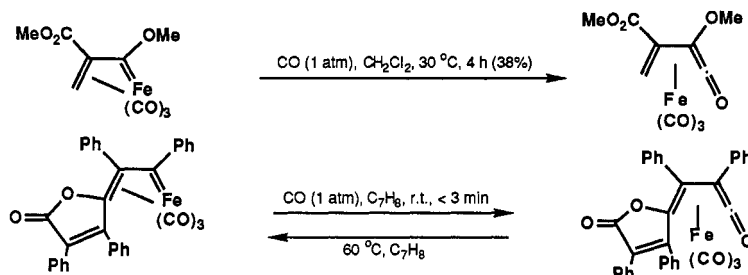
The reactions described above were all performed under a nitrogen atmosphere. More recently we decided to investigate the effect of replacing the nitrogen atmosphere with a carbon monoxide atmosphere. Accordingly we re-examined the reaction of (oxadiene)tricarbonyliron complexes with methyl-lithium but replaced the nitrogen above the reaction mixture with carbon monoxide. The reactions did not produce any 1,4-diketones. They did generate however, crystalline air-stable organometallic complexes which were identified with the aid of X-ray crystallography as tricarbonyliron complexes of vinylketenes (scheme 5) (ref. 9-10).

Scheme 5

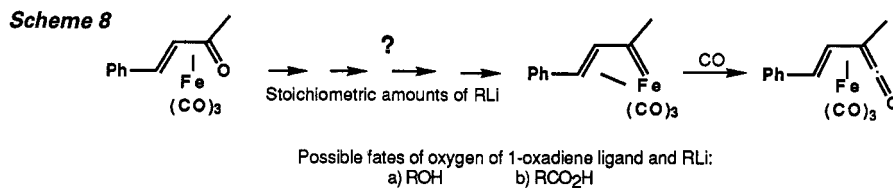
In view of the high reactivity of free vinylketenes and ketenes (ref. 11-15) and the frequent postulation of metal-bound vinylketenes as reaction intermediates (ref. 16-18), we decided that a study of the reactivity of our (vinylketene)tricarbonyliron complexes would prove interesting and rewarding. Before we embarked on these investigations however, we spent some time delineating a reaction pathway for the vinylketone-vinylketene conversion. An experiment which initially appeared to have failed gave the first clue to the route the reaction was following. Having converted several vinylketone complexes to vinylketene complexes, the reaction was attempted with a vinylaldehyde complex. Treatment of (cinnamaldehyde)tricarbonyliron with methyl-lithium under carbon monoxide gave mainly decomposed cinnamaldehyde. Closer examination of the product mixture led however, to the isolation and identification of small amounts of 1,6-diphenylhexatriene and its tricarbonyliron complex (scheme 6) (ref. 10).

Scheme 6

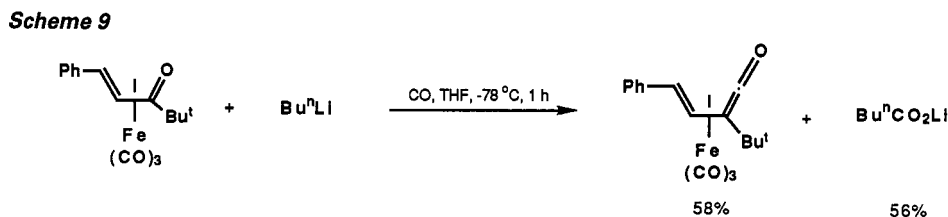
Generation of 1,6-diphenylhexatriene from (cinnamaldehyde)tricarbonyliron suggested that vinylcarbene complexes might be important intermediates *i.e.* that the triene is formed by head-to-head coupling of two vinylcarbene units. Indeed a literature search revealed that there is precedent for the carbonylation of (vinylcarbene)tricarbonyliron complexes to (vinylketene)tricarbonyliron complexes under reaction conditions not too dissimilar to the conditions used for the ketone-ketene transformation (scheme 7) (ref. 19-20).

Scheme 7

Although carbonylation of a (vinylcarbene)tricarbonyliron intermediate would account for the latter stages of the ketone-ketene conversion, the initial steps of the reaction pathway (*i.e.* the vinylketone-vinylcarbene transformation) still posed a problem. In addition the rôle of the alkyl-lithium reagent (of which stoichiometric quantities were required) had still not been determined. And if the carbene-ketene hypothesis was correct, then the oxygen atom in the vinylketone complex needed to be accounted for. Addressing the latter two problems together, it was reasoned that the second product in the ketone-ketene conversion should be either the alcohol derived from the alkyl-lithium reagent used or, given that carbon monoxide is present in excess in the reaction, a carboxylic acid derivative of the alkyl-lithium reagent (scheme 8).

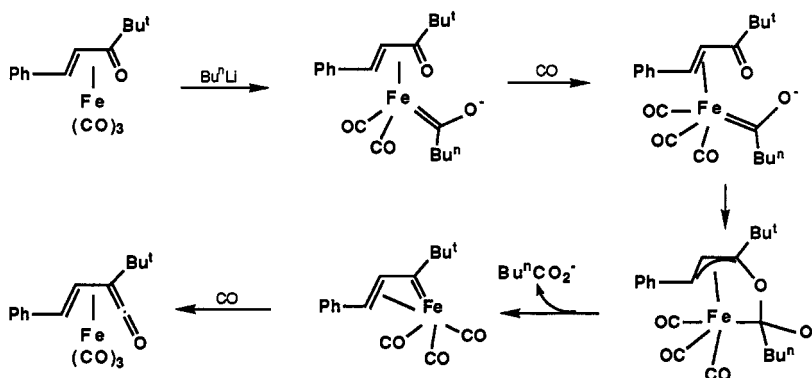


Accordingly in the absence of a proton source it proved possible to isolate lithium pentanoate from a reaction in which BuⁿLi was used as the alkyl-lithium reagent (scheme 9) (ref. 10).



Thus a reaction pathway which incorporates the information described above is shown in scheme 10. Carbonylation of the complex generated by alkyl-lithium attack on a metal carbonyl ligand releases the relatively weakly bound carbon-oxygen double bond of the vinylketone to give a complex which contains a carbon-oxygen double bond and an iron-carbon double bond. These double bonds undergo a metathesis reaction to generate the iron-carbon double bond of the (vinylcarbene)tricarbonyliron intermediate and the carbon-oxygen double bond of the carboxylate salt. Carbonylation of the vinylcarbene complex gives the (vinylketene)tricarbonyliron product.

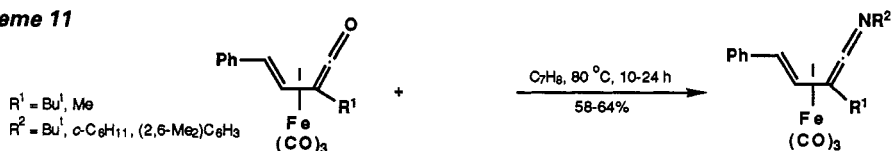
Scheme 10



REACTIONS OF (VINYLKETENE)- AND (VINYLKETENIMINE) TRICARBONYLIRON COMPLEXES

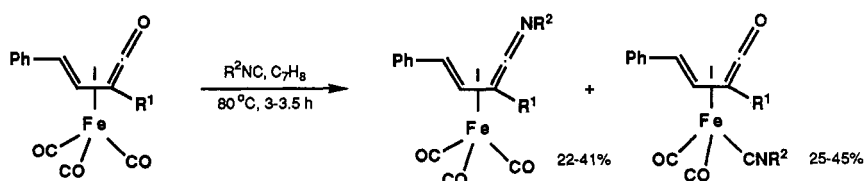
The reaction of (vinylketene)tricarbonyliron complexes with isonitriles was investigated initially. Simply heating (vinylketene)tricarbonyliron complexes with isonitriles at 80 °C gives (vinylketenimine)-tricarbonyliron complexes (scheme 11) (ref. 21 and 10).

Scheme 11

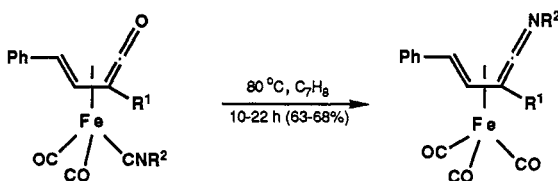


This unprecedented reaction was examined more closely. Firstly, as monitoring the reactions depicted in scheme 11 by t.l.c. had revealed the appearance and disappearance of an intermediate, several of the reactions were halted after 3-3.5 h. The product mixtures contained not only (vinylketenimine)tricarbonyliron complexes but also compounds identified as (vinylketene)dicarbonylisonitrile complexes (scheme 12). These complexes were isolated and converted to (vinylketenimine)tricarbonyliron complexes under the reaction conditions used for the ketene-ketenimine transformation (scheme 13) (ref. 21 and 10).

Scheme 12

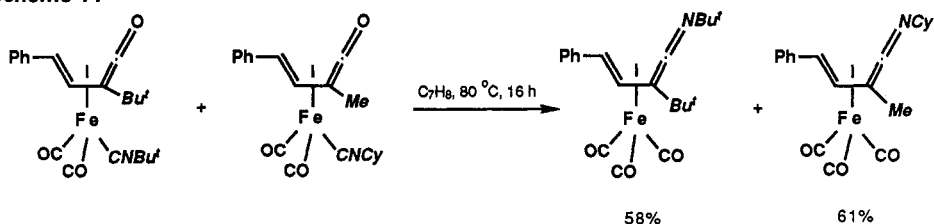


Scheme 13



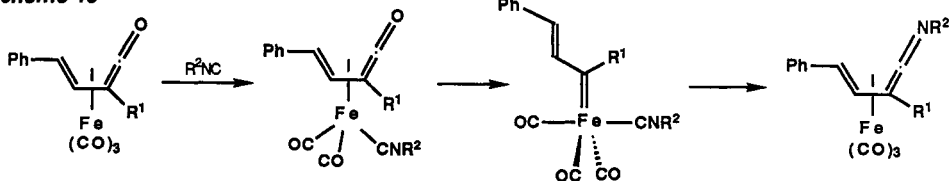
Secondly the two (vinylketene)dicarbonylisonitrileiron complexes depicted in scheme 14 were heated in the same reaction vessel. This gave a product mixture from which the corresponding (vinylketenimine)tricarbonyliron complexes were isolated in yields consistent with yields recorded previously for this reaction. We were unable to detect any evidence for the generation of cross-over products during the experiment and this suggests that the carbonyl/isonitrile exchange occurs intramolecularly (ref. 21 and 10).

Scheme 14



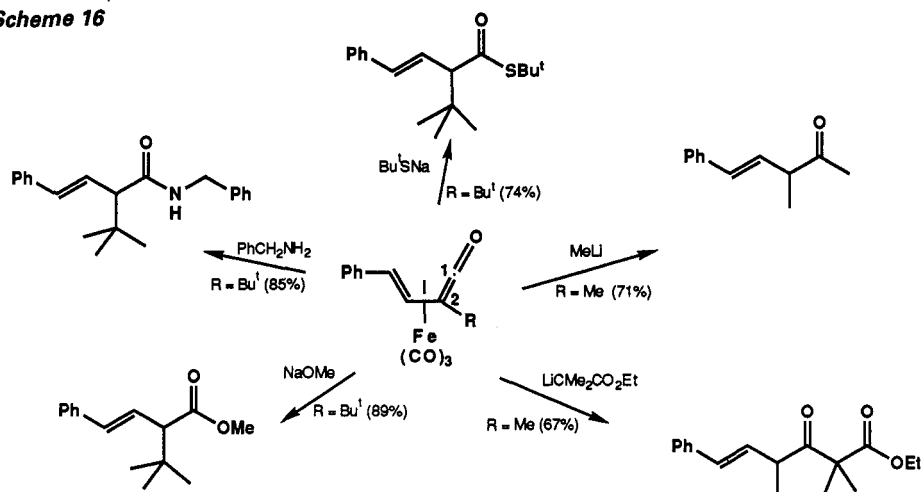
A reaction pathway consistent with these observations is outlined in scheme 15. It is of note that conversion of the (vinylketene)dicarbonylisonitrileiron complex to the (η^1 -vinylcarbene)tricarbonylisonitrileiron species is consistent with the observation (depicted in scheme 7) that heating a (vinylketene)tricarbonyliron complex at 60 °C transformed it into an (η^3 -vinylcarbene)tricarbonyliron complex.

Scheme 15



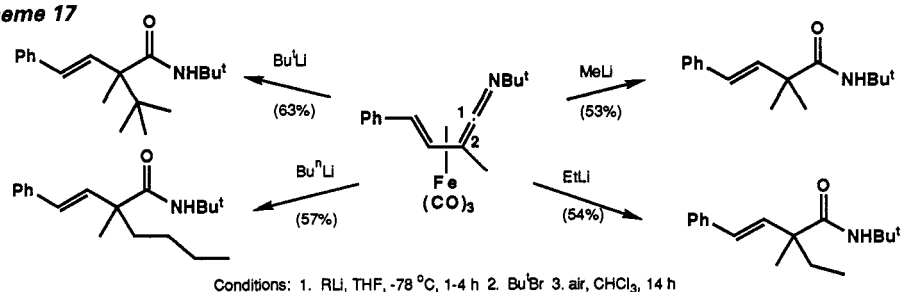
The reactions of (vinylketene)tricarbonyliron complexes with a range of nucleophiles have been examined. As depicted in scheme 16, addition of sulphur, carbon, oxygen, and nitrogen nucleophiles occurs at C-1 to give β,γ -unsaturated carbonyl products (ref. 22).

Scheme 16



Nucleophilic attack on (vinylketenimine)tricarbonyliron complexes has also been examined. It was discovered that alkyl-lithium reagents attack these complexes at C-2 to give, after an oxidative work-up, β,γ -unsaturated amides containing an α quaternary centre. It is of note that the reaction with Bu^tLi gives a product containing two contiguous quaternary centres (scheme 17) (ref. 22).

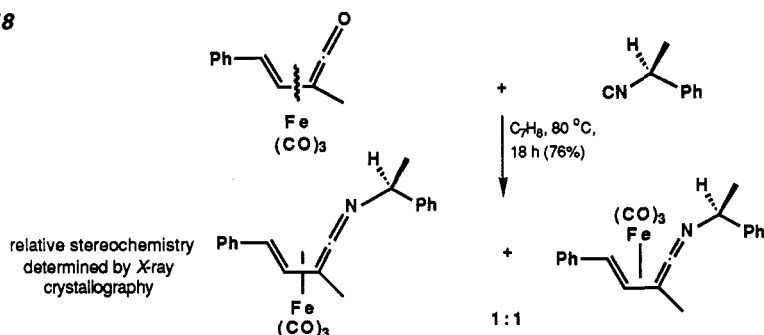
Scheme 17



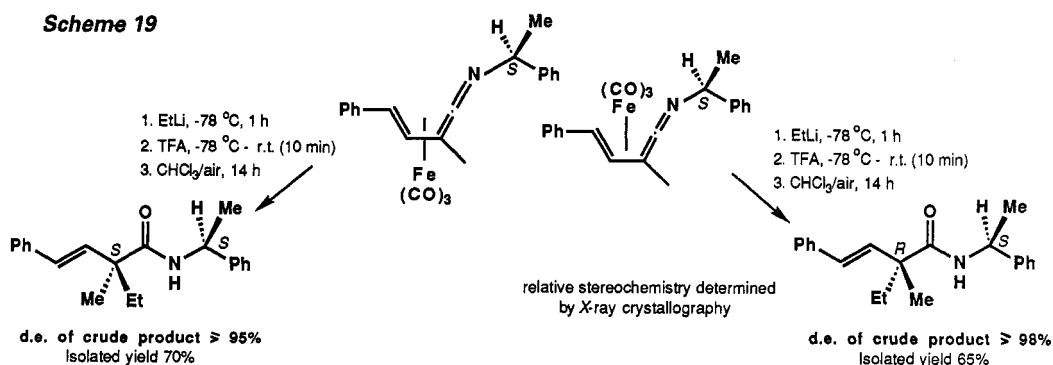
GENERATION OF HOMOCHIRAL QUATERNARY CENTRES

Very recently we have started to look at methods of resolving the organometallic complexes described above with a view to generating homochiral organic products from them. Initial success has been obtained using (*S*)-(-)- α -methylbenzyl isonitrile (readily generated from (*S*)-(-)- α -methylbenzylamine (ref. 23)) to produce (vinylketenimine)tricarbonyliron complexes. Thus heating the optically active isonitrile with the vinylketene complex depicted in scheme 18 gave a 1:1 mixture of diastereoisomeric vinylketenimine complexes. It proved possible to separate the diastereoisomers by column chromatography and the relative stereochemistry of the slower moving diastereoisomer was determined by X-ray crystallography (ref. 24).

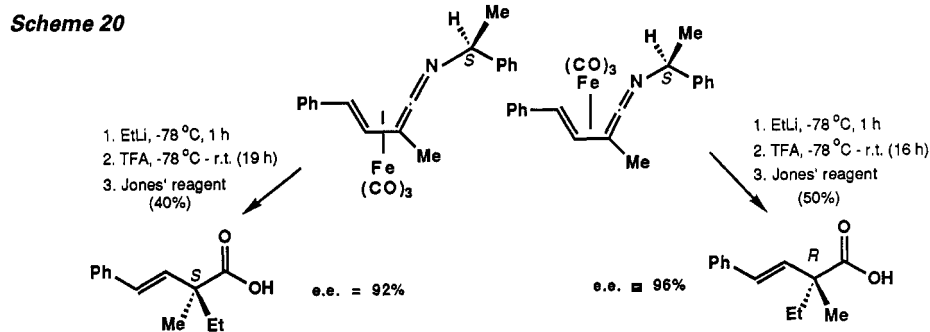
Scheme 18



The stereospecificity and direction of nucleophilic attack on the two diastereoisomers was determined by adding ethyl-lithium to diastereoisomerically pure samples of each diastereoisomer (scheme 19) (ref. 24). Analysis of the β,γ -unsaturated amide products revealed that in each case the nucleophile approached the (vinylketenimine)tricarbonyliron complex exclusively from its *exo* face *i.e.* the face not shielded by the tricarbonyliron unit.



Finally the enantiomeric purity of the quaternary centres produced by this approach was determined. Once again ethyl-lithium was added to samples of each diastereoisomeric complex but in these cases the work-up conditions were altered to produce β,γ -unsaturated carboxylic acids (scheme 20) (ref. 24). The enantiomeric excesses of the carboxylic acids were measured and found to be 92% and 96%. Given that the e.e. of the chiral amine used to prepare the chiral isonitrile was 96% the optical purity of the products appears only to be limited (within experimental error) to the purity of the chiral amine used.



We are currently investigating the scope and applicability of this approach to homochiral quaternary centres.

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