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Iridium-catalyzed hydroiodination of functionalized alkynes

Mehdi Ez-Zoubir [a], Jack A. Brown [b], Virginie Ratovelomanana-Vidal [a,*], Véronique Michelet [a,*]

[a] Laboratoire Charles Friedel, Ecole Nationale Supérieure de Chimie de Paris Chimie ParisTech UMR 7223, 11 rue P. et M. Curie, F-75231 Paris Cedex 05, France
[b] Epinova DPU, II CEDD, GlaxoSmithKline, Medicines Research Centre, Gunnels Wood Road, Stevenage, SG1 2NY, UK

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ABSTRACT

The efficiency of an Ir(I)/HI system has been studied. The association of hydroiodic acid with iridium has been tested in the catalytic hydroiodination of alkynes. The use of $[Ir(cod)Cl]_2$ dimer led to clean hydroiodination reactions and afforded the corresponding vinyliodides as a mixture of derivatives, where the Markovnikov type adduct was found to be the major product (80/20 to 93/7 ratio), in good yields. The mechanism was investigated and two main pathways seemed to be involved, one based on an initial oxidative addition of HI to the Ir(I) complex and the other one based on a π-activation of the alkyne moiety. The corresponding vinyliodides were engaged in Pd-catalyzed cross-coupling (Sonogashira and Suzuki–Miyaura) reactions under organoaqueous conditions.

1. Introduction

The emergence of cross-coupling reactions including Mizoroki-Heck [1], Sonogashira [2] and Suzuki–Miyaura [3] reactions has made the vinyliodide derivatives highly valuable substrates, however their preparation starting from alkynes [4] has been particularly challenging. Historically, various boron halides or metal hydrides in the presence of an iodine source have been used to avoid the use of gaseous hydrogen iodide and to increase the scope of this transformation: haloboration [5], hydroboration, hydrostannylation, hydrozincation or hydrozirconation or hydroindation/I_2 reactions [6] may be cited as seminal examples. Based on Kishi's report [7], a recent example of cuprosilylation followed by NIS (*N*-iodosuccinimide) trapping allowed the formation of functionalized vinyliodides [8]. Selective conditions employing LiI/AcOH or TMSCl/NaI/H_2O systems were found to be efficient for the hydroiodination of propargylic or homopropargylic alcohols and alkylsubstituted alkynes and interestingly led to the Markovnikov adduct [9]. In the case of activated alkynes such as ynones, 1-alkynoic acids or derivatives, these systems afforded the *anti*-Markovnikov iodoalkenes [10].The use of zinc iodide and *tert*-butyl iodide was necessary to promote the mild and selective hydrohalogenation of 3-propynamides [11]. An elegant strategy based on an iodoarylation reaction of arylacetylenes was recently described [12]. The use of molecular iodine [13] in the presence of various acidic additives such as γ-alumina, titanium tetraiodide led in most cases to the alkenyl or alkanyl diiodide [14], whereas the association of I_2 with hydrophosphane afforded the desired iodoalkenes in excellent selectivity [15]. To the best of our knowledge, the groups of Campos, Rodriguez and Mitchenko described unique catalytic systems based on either a mixture of iodine, $CuO.HBF_4$ (50 mol%) and triethylsilane or a platinum(IV) catalyst [16,17]. Mitchenko, Beletskaya and co-workers reported the Pt-catalyzed dimerization of acetylene, which was accompanied by addition of iodine and which led to (*E*, *E*)-1,4-diiodobuta-1,3-diene [18]. The preparation of vinyliodides still requires investigation for functionalized substrates, which are non-compatible with the classical methods. In the course of our study of alkyne and enyne dimerization reactions in the presence of $[Ir_2H_2I_3((rac)\text{-Binap})_2]^+I^-$ [19], we observed the formation of an alkenyliodide resulting from the hydroiodination of the alkynyl moiety. We therefore decided to investigate the possibility of finding a suitable catalyst for the formation of vinyliodide derivatives and wish to present our preliminary results herein.

2. Results and discussion

2.1. Optimization of the catalytic system

Initial efforts have focused on the optimization of an efficient system using dimethyl 2-(prop-2-ynyl)propanedioate **1** as a model

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* Corresponding authors.
E-mail addresses: virginie-vidal@chimie-paristech.fr (V. Ratovelomanana-Vidal), veronique-michelet@chimie-paristech.fr (V. Michelet).

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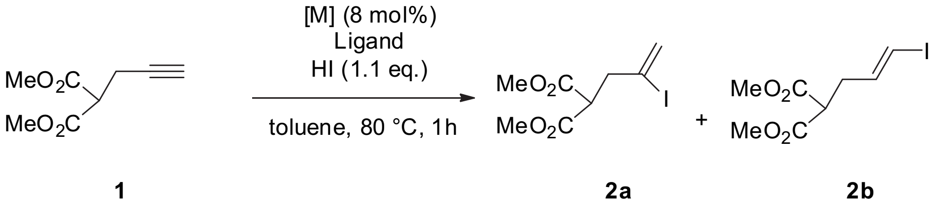
Table 1



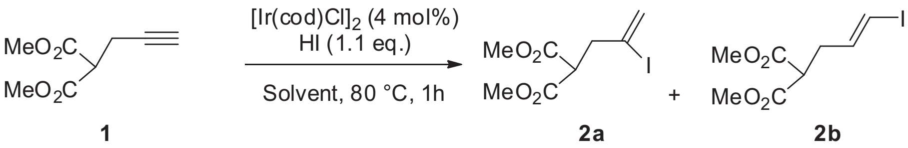
Entry	[M] Catalyst	Ligand (16 mol%)	Conv (%)	**2a/2b** ratio (%)[a]
1	$RuCl_3$	/	32	89/11
2	$IrCl_3$	/	23	>95/5
3[b]	$AuCl_3$	/	8	>95/5
4[b]	AuCl	/	15	>95/5
5	$PdCl_2$	/	35	>95/5
6	$PtCl_2$	/	99 (20[e])	>95/5[c,d]
7	$[Rh(cod)Cl]_2$	/	66	69/31
8	$[Ir(cod)Cl]_2$	/	99 (72[e])	83/17
9[f]	/	/	20	100/0
10[g]	$[Ir(cod)Cl]_2$	PPh_3	99	84/16
11[g]	$[Ir(cod)Cl]_2$	$PPh(Cy)_2$	99	80/20
12[g]	$[Ir(cod)Cl]_2$	$P(Ph)_2Cy$	99	82/18
13[g]	$[Ir(cod)Cl]_2$	$P(p\text{-OMe–}C_6H_4)_3$	99	86/14
14[g]	$[Ir(cod)Cl]_2$	$P(p\text{-}CF_3\text{–}C_6H_4)_3$	99	80/20
15[g]	$[Ir(cod)Cl]_2$	dppf[h]	99	80/20

[a] Determined by ^1H NMR spectroscopy.
[b] Room temperature.
[c] Degradation.
[d] *Z* isomer (10%).
[e] Isolated yield.
[f] Dioxane.
[g] 19 h.
[h] 8 mol%.

substrate. We investigated the use of various organometallic species at 80 °C in toluene (Table 1). In all cases, the reaction employing 8 mol% of catalyst and 1.1 eq. of aqueous hydroiodic acid allowed the formation of iodides **2a** (resulting from a Markovnikov type [20] addition of HI on the triple bond) and **2b** in various ratio, **2a** and **2b** being non-separable by column chromatography. The *E* stereochemistry of **2b** was determined by ^1H NMR spectroscopy considering the coupling constant of the vinylic protons.

Low conversions were observed with $RuCl_3$, $IrCl_3$, $AuCl_3$, AuCl and $PdCl_2$ (Table 1, entries 1–5). Notably, $PtCl_2$ as catalyst offered an excellent reactivity (Table 1, entry 6), but led to several unidentified by-products. The use of Rh(I) and Ir(I) catalysts led to the best results (Table 1, entries 7–8), the mixture **2a/2b** being isolated in 72% yield in the case of the iridium dimer. The importance of the catalyst was demonstrated by performing the reaction without an organometallic species (Table 1, entry 9): a low conversion was observed and the reaction favoured the expected Markovnikov type adduct **2a**. We therefore selected the Ir(I) catalyst and studied the influence of phosphorous ligands on the **2a/2b** ratio (Table 1, entries 10–15). The introduction of an

Table 2



Entry	Solvent	Conv (yield[a]) (%)	**2a/2b** ratio (%)[b]
1[c]	CH_2Cl_2	99	85/15
2	$ClCH_2CH_2Cl$	99	87/13
3[d]	Et_2O	50	100/0
4	MeOH	99 (34)	95/5
5	THF	99 (51)	95/5
6	Dioxane	99 (77)	93/7

[a] Isolated yield.
[b] Determined by ^1H NMR spectroscopy.
[c] 60 °C.
[d] 40 °C, 16 h.