

# Syntheses of fluorous propenes from 3-perfluoroalkyl-2-iodo-1-propanols

Csongor Szíjjártó, Peter Ivanko, Ferenc T. Takács, Dénes Szabó, József Rábai \*

*Institute of Chemistry, Eötvös Loránd University, P. O. Box 32, H-1518, Budapest 112, Hungary*

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Dedicated to Professor Árpád Kucsman on the occasion of his 80th birthday.

## Abstract

3-(Perfluoroalkyl)-1-propenes are obtained in excellent yields up to 100-g quantities by deiodination–dehydroxylation reactions of the easily accessible 2-iodo-3-(perfluoroalkyl)-propanols with red phosphorus and catalytic amounts of iodine or with an  $\text{SnCl}_2/\text{POCl}_3$  reagent pair in pyridine (fluorous Cornforth reaction). Both methods afford fluorous propenes in high GC purity, the former one has high atom-economy and proceeds safely if the fluorous iodohydrin precursors are added in increments; for the solid ones using a ‘hot-melt’ dropping funnel. The title fluorous propenes are effectively isolated by co-distillation with pyridine.

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*Keywords:* Atom-economy; Liquid–liquid phase separation; Fluorine; Fluorous distillation; Propenes

## 1. Introduction

Although many fluorous reagents [1–7] have recently become commercially available [8–10] there is a need for their cost effective synthesis. Perfluoroalkyl iodides are among the most preferred precursors for the synthesis of such compounds [11]. Since fluorous iodohydrins **1a–e** can be made on larger scales by the controlled radical chain addition of perfluoroalkyl iodides to allyl alcohol (Scheme 1), we have recently improved the preparation of 3-perfluoroalkyl-propanols ( $\text{C}_n\text{F}_{2n+1}\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$ ) using hydrazine hydrate and Raney-Ni catalyst for the deiodination reaction of these precursors [12]. Here we thought to develop their conversion into 3-perfluoroalkyl-1-propenes (**2a–e**, Scheme 1), another class of valuable fluorous compounds, which have been used for the synthesis of fluoropolymers [13], fluorous trialkylphosphines [14–16], fluorous boronates [17], polyfluorinated alkanes as potential sky-waxes [18] and alternating copolymers with carbon monoxide [19,20] among others.

Literature syntheses of fluorous propenes involve the reactions of perfluoroalkyl-zinc reagents and allyl-halides [21]; allyl Grignard and  $\text{C}_8\text{F}_{17}\text{I}(\text{Ph})\text{OSO}_2\text{CF}_3$  [22]; tributylallyltin with  $\text{C}_6\text{F}_{13}\text{I}$  and  $\text{Pd}(0)$  [23], or  $\text{C}_8\text{F}_{17}\text{I}$  and AIBN

[14,24], respectively; tributylallylsilane and  $\text{C}_8\text{F}_{17}\text{I}$  at 60 °C with  $\text{Ru}_3(\text{CO})_{12}$  in a sealed tube [25]; allyl-halides and  $\text{C}_n\text{F}_{2n+1}\text{I}$  ( $n = 4,6,8$ ) with AIBN in the presence of freeze-dried KOH [26]; and iodohydrin esters or ethers with Zn [27–29].

The deiodo-dehydroxylation reaction of a perfluoroallyl iodohydrin with zinc in ethylene glycol was reported by Gorbunova et al. and afforded  $\text{CF}_2=\text{CFCF}_2\text{CH}_2\text{CH}=\text{CH}_2$  in good yield [30]. Propenes with longer fluorous chains were prepared from the precursor iodohydrins in 56–60% yields using Zn powder in aqueous acetic acid [18].

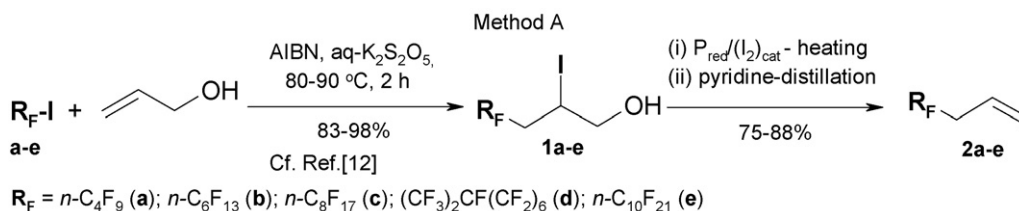
## 2. Results and discussion

First we tried to apply the Gorbunova method for the preparation of **2c**, by heating **1c** with Zn in ethylene glycol at ~140 °C for 1 h. However, our efforts resulted only in the formation of a mixture of **2c** (47%) and the corresponding saturated alcohol,  $\text{C}_8\text{F}_{17}(\text{CH}_2)_3\text{OH}$  (**3c**, 22%). Propene **2c** was isolated from the lower layer of its rather volatile co-distillate with ethylene glycol (bp ~125 °C), which in the condenser turned into two immiscible liquid phases; while alcohol **3c** came over at higher temperature (bp ~160 °C) and with larger volume of the co-distilling ethylene glycol, from which on cooling it was phase separated as a colourless crystalline solid.

It should be noted that the immiscibility of these fluorous components and ethylene glycol resulted in their co-distillation

\* Corresponding author. Fax: +36 1 372 2592.

E-mail address: [rabai@elte.hu](mailto:rabai@elte.hu) (J. Rábai).



Scheme 1. Preparation of fluorous olefins **2a–e** with the deiodo-dehydroxylation reaction of easily made fluorous iodohydrins **1a–e**.

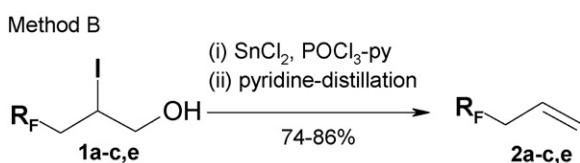
at significantly lower temperatures than their normal boiling points. This phenomenon is analogous to steam-distillation and we named it as ‘*fluorous distillation*’ for ethylene glycol, or in short as ‘*glycol-distillation*’ of fluorous propenes. In principle this separation is governed by the same physical–chemical rules that apply to the perfluorocarbon facilitated esterification reactions reported first by Zhu [31].

Then, we tested the Cornforth-procedure, which method has originally been introduced for the transformations of non-fluorinated iodohydrins into internal olefins [32]. Although fluorous propenes **2** can be obtained in excellent yields applying the Cornforth-method using an  $\text{SnCl}_2/\text{POCl}_3$  pyridine system, this method involves some drawbacks: the formation of toxic white phosphorus as side product, which has to be destroyed with an excess of iodine before work-up started, according to the warning given by Cornforth et al. [32], and a lower atom economy [33] with an anticipated raising of waste disposal costs (Scheme 2).

However, we have recognized that the tedious extractive workup procedure of Cornforth et al. can be substituted by co-distillation of the volatile fluorous alkenes with pyridine. This process can be named as ‘*fluorous distillation*’ for pyridine or in short as ‘*pyridine-distillation*’ of fluorous propenes. Another useful property of pyridine–fluorous alkene mixtures is the quick phase separation of the colourless distillate into a lower fluorous olefin and a top pyridine layer on cooling from boiling to room (**2b–e**) or lower temperatures (**2a**). Solvent tuning [34,35] by the addition of water to the pyridine layer results in practically complete separations of these olefins.

Consecutive washing of the lower layers with water, 5% aqueous HCl, and water, and drying ( $\text{Na}_2\text{SO}_4$ ), followed by short path distillation affords these olefins in high yields and purity (GC assay). It should also be commented that all of these aqueous washings can be performed without the addition of ether or other solvents. We named this procedure as ‘*concentrate workup*’ since the fluorous layers are not diluted here with miscible solvents.

We disclose here a novel and convenient method for the preparation and isolation of fluorous propenes **2a–e** in high yields and GC purities, which furthermore eliminates the drawback of



Scheme 2. Preparation of fluorous propenes with a modified Cornforth protocol.

the modified Cornforth procedure. This protocol involves the reaction of iodohydrins **1a–e** with red phosphorus ( $\geq 0.66$  g-atom/mol) and catalytic amount of iodine without any added solvents at 100–130 °C. When the reaction is over pyridine is added to the reaction mixture to allow product isolation using novel separation techniques called as ‘*pyridine-distillation*’ and ‘*concentrate work-up*’ procedures (Method A, Scheme 1).

We consider this reaction as an autocatalytic one: the trace amount of iodine first reacts with red phosphorus to provide phosphorus triiodide, which then converts the iodohydrins into the thermally unstable 1,2-diiodo-3-(perfluoroalkyl)-propane intermediates, and their decomposition gives rise to the formation of more iodine and fluorous propene. Finally all of the substrate is being converted to propenes, along with the formation of iodine and phosphorous acid side products (Scheme 3).

Our original procedure (Method A, Scheme 1) seems to compete with the best reported ones in yields (*vide supra*), but overcomes them having a better atom economy and access to precursors. However, on larger scales ( $>50$  g) the reaction should be controlled by the incremental addition of **1a–e** (cf. Section 3).

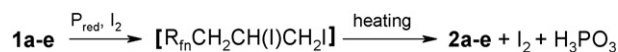
In summary fluorous propenes **2a–e** were prepared in excellent yields from ten to several-hundred-gram scales, and were isolated with novel fluorous techniques based on their inherent volatility and immiscibility with pyridine (**2b–e**) or aqueous pyridine (**2a–e**), and were distilled to reach GC purities higher than 99.0%.

All fluorous products were characterized by their boiling point and/or melting point, GC analysis of neat samples, and NMR ( $^1\text{H}$ ,  $^{13}\text{C}$ ,  $^{19}\text{F}$ ) spectroscopy, showing agreeable patterns with reported ones (cf. Section 3). They are all easily moving liquids or low melting solids; volatile with pyridine, ethylene glycol or steam; immiscible in most polar solvents (e.g. water, ethylene glycol, methanol, pyridine); while miscible in ether, acetone, benzotrifluoride, perfluoro(methylcyclohexane), and other fluorous solvents at ambient temperature.

### 3. Experimental

#### 3.1. Methods

$^1\text{H}$ ,  $^{13}\text{C}$  and  $^{19}\text{F}$  NMR spectra were recorded on Bruker Avance 250 using a 5 mm inverse  $^1\text{H}/^{13}\text{C}/^{31}\text{P}/^{19}\text{F}$  probe head at



Scheme 3. Supposed pathway for the deiodo-dehydroxylation reaction of fluorous iodohydrins **1a–e** with red phosphorus and iodine catalyst.

room temperature. Melting points were determined on a Boetius micro-melting point apparatus and are uncorrected. All reaction steps were monitored by gas chromatography (Hewlett-Packard 5890 Series II, PONA [crosslinked methyl-silicone gum] 50 m × 0.2 mm × 0.5 μm column, H<sub>2</sub> carrier gas, FID detection).

The 'hot-melt' dropping funnel is a simple apparatus that allows the incremental addition of solids under an inert atmosphere. The apparatus was fabricated from an ST 29/32 female and an ST 14/23 male joint, both 60 mm long and a 120 mm length of 38 mm glass tubing. The joints were flared to the glass tubing. For using the apparatus it was fixed in an upright position and a small T shaped glass stopper (15 mm × 6 mm × 25 mm) was placed in to prevent the falling down of the solids when they are charged into the funnel. The 'hot-melt' dropping funnel can be charged with more iodohydrin which estimated by its powder density, if it is partially melted during the loading process. Finally the apparatus was closed with an ST 29/32 stop-cock and fitted to the three-necked reactor. The addition rate of the fluorous iodohydrins was easily controlled by heating the lower end of the funnel using a 'hot-air' heat gun since the T-shaped glass stopper means no barrier for dropping down the melt.

The fabrication and use of an improved dropping funnel for liquid or melt additions has been disclosed in [36].

### 3.2. General methodology for the preparation of fluorous propenes using red phosphorus with catalytic amounts of iodine (Method A)

A 500 mL round-bottomed three-necked flask was provided with a magnetic stirrer bar and equipped with a thermometer, pressure equalizing dropping funnel and a condenser with argon-by-pass, connected to an acid trap containing dilute sodium hydroxide solution through an empty gas wash bottle. Then it was flushed with argon and then charged with red phosphorus (12.7 g, 410 mmol) and iodine (3.05 g, 12.0 mmol). The mixture was stirred and heated to 60–80 °C with an oil bath until all iodine has reacted, which was indicated by the disappearance of the violet colour of iodine vapours. Then the temperature of the oil-bath was slowly heated to 110–125 °C while iodohydrin **1a** (242 g, 600 mmol) was added drop-by-drop to the stirred reaction mixture during 1 h to allow the controlled boiling of the product formed (**2a**) at an internal temperature of 100–110 °C. The mixture was further stirred at 120 °C bath until all iodine vapours disappeared (1 h), then cooled to 80 °C and mixed with pyridine (160 mL). The reflux condenser was changed to a distillation head and the main fraction of the co-distillate (80 mL) was collected in the boiling range of 80–82 °C. The distillate was diluted with water (80 mL), and the separated lower fluorous layer was washed with water (20 mL), 5% aq-HCl (3 × 20 mL), water (20 mL), dried (Na<sub>2</sub>SO<sub>4</sub>) and filtered to afford **2a** (117 g, 75%, GC assay: 99.8%).

The next fraction of the co-distillate of py-@-**2a** (40 mL) was collected between 82 and 115 °C, which on an aqueous

workup (*vide supra*) gave a second but less pure crop of **2a** (6.4 g, GC: 98.2%).

The reactions of **1b** and **1c** were performed analogously using molar ratios of 1/P/I<sub>2</sub> = 50:34:1 as above, but using a 'hot-melt' dropping funnel for the introduction of iodohydrins **1b** and **1c**, and using more pyridine for co-distillation of py-@-**2b** with bp 108–110 °C and py-@-**2c** with bp 113–115 °C, respectively. In general 0.5–2.0 mL of pyridine was added for each gram of the starting iodohydrins. Some pyridine can be saved in these processes by using a Dean-Stark separator for larger scale preparations.

Small scale reactions with **1d** and **1e** iodohydrins were performed in heavy walled Pyrex tubes behind a safety shield using the same molar ratios of 1/P/I<sub>2</sub> as above. They were stirred in an oil-bath at 120–130 °C until the colour of iodine disappeared (2 h), then allowed to cool to room temperature and then frozen at –78 °C and carefully opened in a hood using a hydrogen torch. At this moment and during their warming to ambient temperature some gas was released from the open ampoules. Their content was melted using a hot air 'heat-gun' and transferred into a distillation apparatus. **2d** and **2e** were isolated by co-distillation with pyridine followed by *concentrate* work-up or filtration, respectively. They can be further purified by distillation.

#### 3.2.1. Preparation of 4,4,5,5,6,6,7,7,7-nonafluoro-1-heptene (**2a**)

The reaction was performed according to Method A using **1a** (242 g, 0.60 mol). Yield: 117 g (75%) colourless oil; GC assay: 99.8%. Bp 81–83 °C. The spectroscopic data were in agreement with those reported [37].

#### 3.2.2. Preparation of 4,4,5,5,6,6,7,7,8,8,9,9,9-tridecafluoro-1-nonene (**2b**)

The reaction was performed according to Method A using **1b** (126 g, 0.25 mol). Yield: 75.4 g (84%) colourless oil; GC assay: 99.2%. Bp 123–124 °C. The spectroscopic data were in agreement with those reported [37].

#### 3.2.3. Preparation of 4,4,5,5,6,6,7,7,8,8,9,9,10,10,11,11,11-heptadecafluoro-1-undecene (**2c**)

The reaction was performed according to Method A using **1c** (242 g, 0.40 mol). The product obtained by pyridine distillation and *concentrate* work-up was filtered to afford a pure crude product. Yield: 162 g (88%) colourless oil; GC assay: 99.0%. Bp 164–166 °C. The spectroscopic data were in agreement with those reported [37].

#### 3.2.4. Preparation of 4,4,5,5,6,6,7,7,8,8,9,9,10,11,11,11-hexadecafluoro-10-trifluoromethyl-1-undecene (**2d**)

The reaction was performed according to Method A using **1d** (9.81 g, 15 mmol). The product obtained by pyridine distillation and *concentrate* work-up was purified by fractional distillation. Yield: 5.81 g (76%) colourless oil; bp 80–82 °C/16 mmHg. GC assay: 97.7%. The spectroscopic data were in agreement with those reported [24].

### 3.2.5. Preparation of 4,4,5,5,6,6,7,7,8,8,9,9,10,10,11,11,11-eicosafuoro-1-tridecene (**2e**)

The reaction was performed according to Method A using **1d** (10.6 g, 15 mmol). The crude product obtained by pyridine distillation and ether extraction was purified by fractional distillation. Yield: 6.80 g (81%) white crystalline solid; GC: 95.7%. Mp 31–32 °C, bp 95–96 °C/16 mmHg. The spectroscopic data were in agreement with those reported [24].

### 3.3. Preparation of fluorous propenes using a pyridine–SnCl<sub>2</sub>/POCl<sub>3</sub> system (Method B)

A 250 mL round-bottomed flask was charged with a magnetic stirrer bar, the iodohydrin **1** (40 mmol), absolute pyridine (72 mL), powdered SnCl<sub>2</sub> (20 g, 105 mmol), then POCl<sub>3</sub> (8.2 g, 54 mmol) in pyridine (14 mL) was added drop-by-drop to the mixture. Then it was closed with a CaCl<sub>2</sub> drying tube and kept in the hood at room temperature for 7 days. Next, the mixture was treated with iodine (21 g, 83 mmol) in pyridine (50 mL) to destroy all yellow phosphorous has been formed as a side product (**Caution**: Toxic). Then the flask was fitted with a distillation head and condenser, and heated to 160 °C with an oil-bath. The higher fluorous propenes **2b–e** co-distilling with pyridine were spontaneously phase separated on cooling, while the less fluorous **2a** was separated as a lower layer only after water was added to the colourless distillate (**py-2a**). The separated pyridine layers were returned two or three times to the boiling flask to ensure complete transfer of fluorous propenes to the receiver flask with the advantage of using less amount of pyridine. At the endpoint the pot temperature has reached 115 °C, the normal boiling point of pure pyridine. Then the distillate was diluted with ice-cold water (40 mL), and the phase separated product layers were subjected to ‘concentrate workup’. They were washed with 2M aq-HCl (3 × 5 mL), water (3 × 5 mL), dried (Na<sub>2</sub>SO<sub>4</sub>) and filtered. They can further purified by distillation.

These reactions were performed using **1a** (16.2 g, 40 mmol); **1b** (20.2 g, 40 mmol); **1c** (72.5 g, 120 mmol); and **1e** (14.1 g, 20 mmol) to afford **2a**: 7.70 g (74%) colourless oil, GC assay: 98.8%; **2b**: 11.2 g (78%) colourless oil, GC assay: 98.5%; **2c**: 47.7 g (86%) colourless oil, GC assay: 99.8%; or **2e**: 9.41 g (84%) white solid, GC assay: 96.5%; respectively. The spectroscopic data were in agreement with those obtained under Method A.

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