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ANODIC FUNCTIONALIZATION OF VINYL SULFIDES. FORMAL ACCESS TO *GEM* OR VICINAL ARYL THIOETHER DICATIONS

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Key Words : vinyl sulfides ; enol thioethers ; anodic oxidation ; electrochemistry ; fluorination ; methoxylation ; acetoxylation ; formal dication ; fluorosulfides.

Abstract : The anodic oxidation of a number of vinyl thioethers has been performed in CH_3CN-Et_3N,3HF. Results clearly show that the reactivity of the vinyl sulfide radical cation depends on several factors as structure of substrates and nucleophilic conditions. For example a dimerization occurred from the unsubstituted vinyl sulfide **1a** (CH_2=CH-SPh) whereas α,β- and/or β,β-difluoro sulfides were obtained from substituted homologues. In order to understand this reactivity the anodic behaviour of **1a** and **1b** (Ph-CH=CH-SPh) has been especially analysed in two other nucleophilic media (CH_3OH/Et_3N,3HF and AcOH/AcOK) leading respectively to methoxylation and acetoxylation of starting compounds. Comparison with electrofluorination results has allowed us to propose a mechanism involving an intermediary episulfonium ion which could explain the formation and ratio of the products isolated.

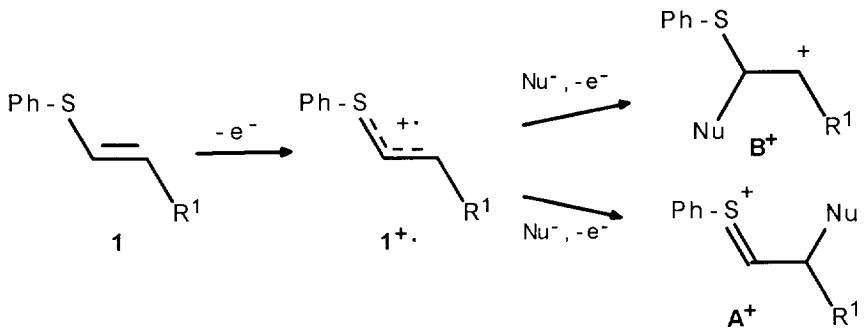
INTRODUCTION

Owing to their usefulness in organic synthesis, the reactivity of enol derivatives has been extensively studied. Thus, electrooxidation of enol acetates, enol ethers and enol silylethers has been examined mainly in order to obtain masked or unmasked α functionalized ketones[1]. The anodic oxidation mechanism involves the inversion of the polarity of the substrate by an electron transfer, and a double nucleophilic addition at the carbon-carbon double bond takes place. Despite the fact that several problems may occur such as the dimerization of radical cations from enol ethers[2] or the formation of α,β-enone by-products during the electrolysis of enol acetates[3], this electrochemical process is effective for the preparation of α-methoxy[4], α-acetoxy[5] or α-fluoro ketones[6] in relatively good yields.

In contrast, anodic oxidation of unsaturated thioethers has been relatively unexplored although valuable synthetic intermediates can be obtained by functionalization of the double bond or by C-S bond cleavage[7]. In fact only the anodic oxidation of substituted styryl phenyl sulfides has been investigated. In aqueous acetonitrile, α-thiolated aldehydes[8] were obtained, while in methanolic solution α-thiolated dimethoxy acetal or α,β-dimethoxy thioethers were isolated depending on the other substituents[9].

On the other hand, Craig *et al.*[10] have demonstrated that vinyl sulfoxides could be considered as thioether α,β-dication equivalents in reactions involving a strong electrophilic species (Additive Pummerer Reaction). For example, a double α,β-trifluoro acetoxylation of the double bond was observed when phenyl vinyl sulfoxides were submitted to trifluoro acetic anhydride in methylene chloride. Recently, this approach has been used by Viehe and colleagues[11] to obtain *bis* C-alkylation of the double bond. This last reaction was thus very similar to the anodic oxidation of vinyl sulfides in terms of concept and potentialities. We therefore decided to re-examine the anodic behaviour of a number of enol thioethers.

In view of previous results in this field, it is possible that the first anodic oxidation step will produce a radical cation $\mathbf{1}^{+\cdot}$ which is immediately trapped by a nucleophile. A second electron loss step then leads to an α or β thiocarbenium ion (scheme 1).



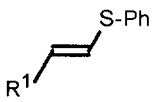
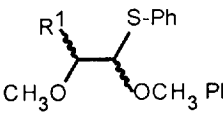
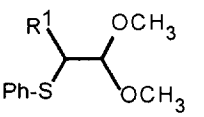
Scheme 1

Since the regioselectivity of the first nucleophilic attack might be related both to the substrate and to the nucleophilic reactant, anodic oxidations of two representative vinyl sulfides have been performed in three different media, including methoxylating, acetoxylating and fluorinating conditions. We hereby report our main results and suggest a slightly different mechanistic pathway from that previously postulated[9], in order to explain them.

RESULTS AND DISCUSSION

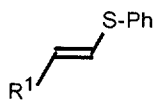
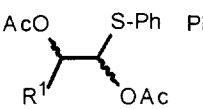
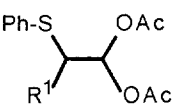
Whatever the electrolytic conditions, preparative scale electrolyses were carried out potentiostatically at a platinum anode without separation of the compartment cell. The value of the working potential was always adjusted at the trough of the first oxidation wave as determined by a cyclic voltammetry technique. Methoxylations were obtained following Surowiec and Fuchigami's conditions ($CH_3OH/Et_3N,3HF$)[12] ; acetoxylations were performed in acetic acid containing potassium acetate (1M) whilst electrofluorinations were made in $CH_3CN/Et_3N,3HF$ solution[13]. The results of all our preparative runs are compiled in tables 1, 2 and 3 with respect to the methoxylation, acetoxylation and fluorination of substrates **1**.

Table 1 - Methoxylations[a]

Starting Materials	E (V)[b] applied	F. Mol^{-1}	Products (yield %)[c,d]	
				
1 (E+Z)			**2**	**3**
1a : R^1 = H	1.0	2.5	**2a** (68 %)	
1b : R^1 = Ph	1.0	3.2	**2b** (6 %)	**3b** (57 %)

a) Except where otherwise stated, oxidations were performed until > 95 % of the substrate had reacted (tables 1, 2, 3).
b) *vs* Pleskov electrode (tables 1, 2, 3).
c) Isolated yields unless otherwise noted (tables 1, 2, 3).
d) Other identified side product : Ph-SS-Ph (14 % from **1a** , 18 % from **1b**)

Table 2 - Acetoxylations

Starting Materials	E (V) applied	F. Mol^{-1}	Products (yield %)	
				
1 (E+Z)			**4**	**5**
1a : R^1 = H	1.0	2.5	**4a** (39 %)[a]	
1b : R^1 = Ph	1.0	2.3	**4b** (20 %)	**5b** (50 %)

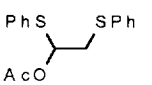
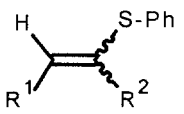
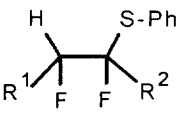
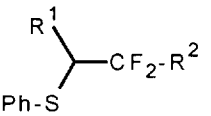
a) Other identified side products from **1a** : Ph-SS-Ph (28 %) ;  (10 %).

Table 3 - Fluorinations

Starting Materials	E (V) applied	F. Mol^{-1}	Products (yield %)	
 **1 (E+Z)**			 **6**	 **7**
1a : R^1=R^2=H	1.0	3.2	**6a** (≈ 8 %)[a,b,c]	
1b : R^1=Ph, R^2=H	1.0	2.5	**6b** (72 %)[a]	
1c : R^1=R^2=Ph	0.9	2.2	**6c** (35 %)[a,d]	**7c** (35 %)
1d : R^1=Ph, R^2=CH_3	1.0	2.5	**6d** (37 %)[c]	**7d** (30 %)[c]
1e : R^1=Ph, R^2=CO_2CH_3	1.2	3.5	**6e** (75 %)	
1f : R^1=CO_2CH_3, R^2=H	1.4	2.3	**6f** (78 %)[d]	
1g : R^1=$COCH_3$,R^2=H	1.4	2.9	**6g** (29 %)[a,c,d]	
1h : R^1,R^2=-$(CH_2)_4$-	1.0	2.6	**6h** (35 %)[c]	

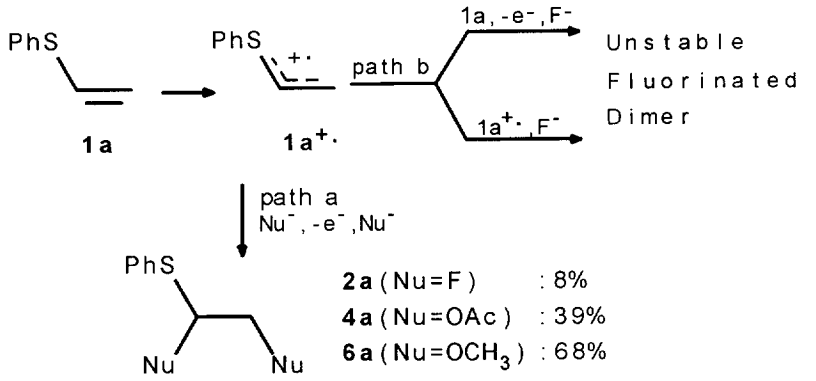
a) Other identified side products : PhS-CHF-CH_2NHAc **8a** (23 % from **1a**) ; Ph-SS-Ph (10 % from **1b**) and (29 % from **1c**) ; PhS-CH=CF-$COCH_3$ **8g** (19 % from **1g**) (see text on next pages).

b) Identified by mass spectrometry and ^{19}F NMR.

c) Evaluated yields by ^{19}F NMR of crude electrolysis with $PhCF_3$ as internal standard.

d) Conversion rate : 94 % from **1c**, 93 % from **1f**, 85 % from **1g.**

Except for electrofluorination of **1a** and **1h**, chemical yields of functionalized sulfides are relatively attractive in as much as it seems difficult to prepare them by classical chemical routes. In particular, α,β-difluorosulfide preparations have not previously been reported. Unfortunately, electrofluorination of **1a** provided a difluoro adduct **6a** in a very low yield (table 3) whilst the methoxylation or acetoxylation of the same substrate did not give rise to any problems. Thus, the dimethoxy adduct **2a** (table 1) and the diacetoxy compound **4a** (table 2) were isolated in respectively 68 % and 39 % yield. For derivative **1a**, the main isolated product was in fact a very unstable fluorinated dimer whatever the level of the working potential (0.8 V or 1.0 V). Despite several attempts to characterize this dimer, purification was unsuccessful. We think that the weaker nucleophilicity of $H_2F_3^-$ relative to AcO^- or CH_3OH is responsible for this difference (scheme 2). A strong nucleophilic medium would favour the formation of disubstituted monomers (path a) whereas a dimerization occurs in less nucleophilic conditions (path b).



Scheme 2

In the anodic oxidation of enol derivatives, it is well known that electrolytic conditions and β-alkyl substitution of the substrate are two factors which can change the ratio between dimerized products and disubstituted monomers[1a]. Moreover, this unwanted dimerization is not observed from other β substituted vinyl sulfides, even in fluorination.

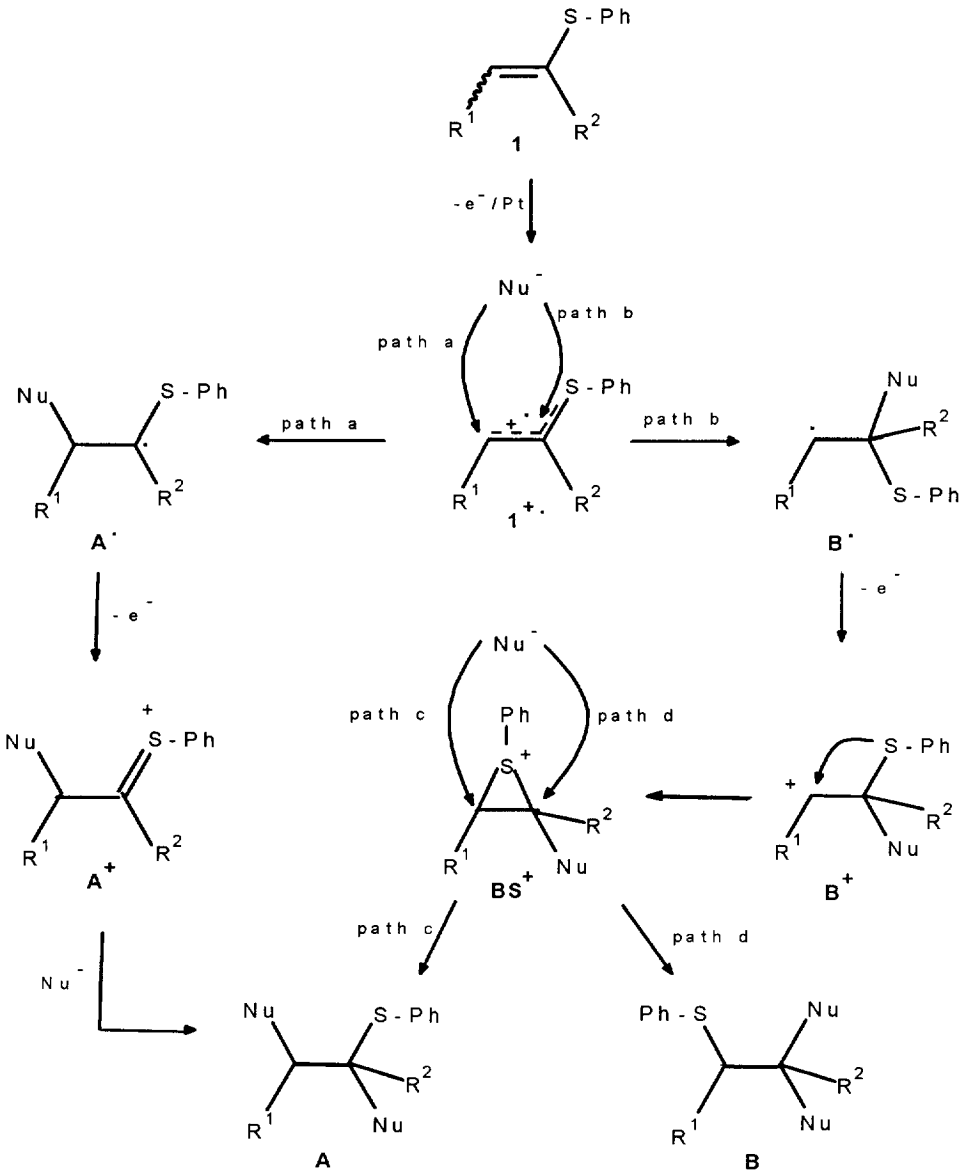
In contrast, anodic oxidation of **1b** involves products resulting from nucleophilic addition at the double bond whatever the nucleophile used. Table 4 reports the relative ratio between vicinal (**A**) and geminal adduct (**B**) observed after oxidation of **1b** in three media.

Table 4 - Oxidation of* 1b. *Ratio between vicinal (A) and geminal adduct (B)*

Nucleophile	Products A	Products B	% A/B
CH_3O	**2b** (6 %)	**3b** (57 %)	9/91
AcO	**4b** (20 %)	**5b** (50 %)	28/78
F	**6b** (72 %)		100/0

* The same potential was applied in all cases

Electrolyses in CH_3OH and AcOH afforded acetal derivatives **3b** and **5b** respectively as major and α,β difunctionalised sulfides **2b** and **4b** as minor products. This last vicinal diaddition was obtained exclusively in Et_3N,3HF leading to α,β-difluorosulfide **6b**. Le Guillanton and Simonet[9] have suggested the formation of an unclassic ion to explain their results concerning the anodic methoxylation of this same sulfide **1b**, but a classical ECEC process for other substrates. On the basis of our own results we propose a slightly modified mechanism (scheme 3) which could particularly rationalize the product distribution described in table 4.



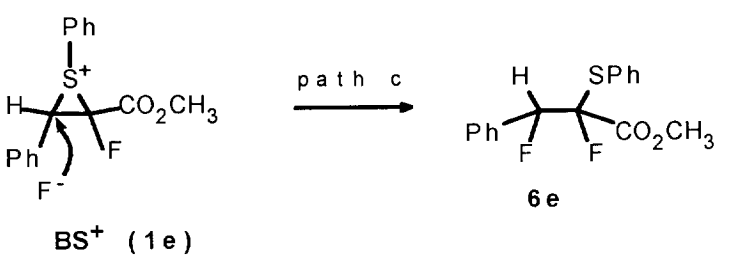
Scheme 3

The first step involves the regioselective nucleophilic attack of $\mathbf{1}^{+\cdot}$ giving rise to intermediary radicals **A**· or **B**·, which are further oxidized to cations $\mathbf{A}^{+}$ and $\mathbf{B}^{+}$. An electrostatic interaction or an orbital control must direct this regioselectivity, depending on the structure of the substrate and the nature of the nucleophile, but it cannot be completely excluded that the stability of

the radical formed should be considered. In this case it should be noted that **A·** is stabilised by S conjugation whereas **B·** could be preferably stabilized by an anomeric effect[14]. Of course, such a stabilization would be enhanced by a phenyl substituent as in **1b** (R^1=Ph). We further suggest that cation $\mathbf{B^+}$ is transformed into an episulfonium ion $\mathbf{BS^+}$ which could be opened by a nucleophile following path c or path d in connection with the relative stabilizing power of R^1 and R^2, Nu substituents *vs* a carbonium ion. It is known that the opening of thiiranium by CH_3OH, AcOH and fluoride anion proceeds generally regioselectively to produce Markovnikov oriented products[15]. On the basis of the thermodynamic properties of the methyl cation[16] it would be expected that the range of stabilizing power is as follows : CH_3O > Ph > F. Thus, the results given in table 4 for compound **1b** (R^1=Ph, R^2=H) can be correctly explained by invoking this pathway. The regioselective opening of the cyclic sulfonium $\mathbf{BS^+}$ follows path c in fluorination (Ph > Nu = F) whereas path d is almost exclusively observed in methoxylation (Nu = CH_3O > Ph) or acetoxylation. Since an acetoxy group is less efficient than a methoxy in stabilizing a carbonium ion, the regioselectivity is less pronounced. Finally, the presence of *gem* difluoro sulfides **7c,7d** isolated from electrofluorination of **1c,1d** confirmed our assumption concerning the involvement of $\mathbf{BS^+}$ ion.

The structure of the acetamido fluoro sulfide **8a** detected from electrofluorination of **1a** (table 3) proves that regioselective attack by fluoride anion according to path b might also be operating for this substrate. Firstly, direct nucleophilic attack of a radical cation by acetonitrile is rather unknown and secondly it has been demonstrated that acetamide results form a competitive reaction on unstable carbocations[17]. In this case, **8a** probably results from nucleophilic attack on reactive ion $\mathbf{B^+(1a)}$ before evolution to $\mathbf{BS^+(1a)}$.

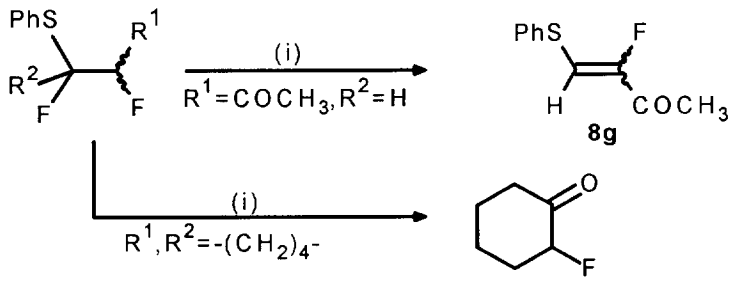
On the other hand, it is necessary to assume that methoxylation of **1a,** acetoxylation of **1a** and fluorination of **1f**, **1g**, **1h** proceed according to path a (scheme 3). Otherwise the path b would strictly lead to *gem* difunctionalisation since the stabilising effect of Nu substituent against a carbonium ion would be better than R^1 (**1a** : R^1=H ; **1f** : R^1=CO_2CH_3 ; **1g** : R^1=$COCH_3$; **1h** : R^1= -CH_2 -). But it is more difficult to decide from **1e** because regiospecific opening of $\mathbf{BS^+}$ **(1e)** leading to vicinal difluorination could quite occur (scheme 4).



$\mathbf{BS^+}$ **(1 e)** **6 e**

Scheme 4

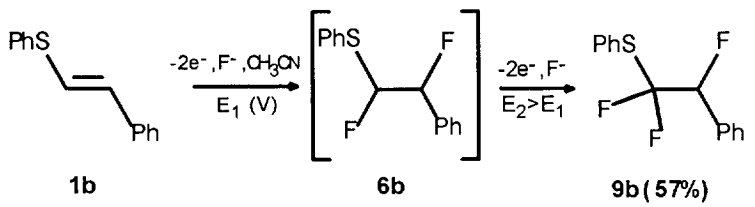
From the synthetic point of view, it is worth noting that α,β-difluorosulfides are sensitive to acids[18] and therefore must be carefully purified using small amounts of Et_3N in eluting solvent. However, such a basic treatment induced deshydrofluorination of **1g** to α fluoro vinyl sulfide **8g** and converted one diastereoisomer of **6h** to α-fluorocyclohexanone[19] (scheme 5).



(i) : light petroleum/Et_3N (97/3)-SiO_2

Scheme 5

Finally as demonstrated by an other group[20] and one of us[21], we have access to α,α,β-trifluorinated sulfide **9b** by a one pot reaction from vinylsulfide **1b** (scheme 6).



Scheme 6

CONCLUSION

In summary, these preliminary results show that enol thioethers are easily functionalized by anodic oxidation. Despite the fact that the mechanistic pathway has not been completely elucidated, this process permits the preparation of α,β-disubstituted sulfides, which can be considered as protected α fluoroaldehydes or ketones. We are currently working to expand the synthetic usefulness of α,β-difluorosulfides by transformations involving the reactivity of the sulfur atom.

EXPERIMENTAL SECTION

I - GENERALITIES

a) - Analyses : ^1H NMR spectra (TMS, $CDCl_3$, ppm, Hz) were carried out on a BRUKER AC 200 (200 MHz). ^{13}C NMR spectra (TMS, $CDCl_3$) were measured at 50.3 MHz on a BRUKER AC 200 whilst ^{19}F NMR ($CFCl_3$, $CDCl_3$) were registered on the same apparatus at 188.2 MHz. Mass

spectra (MS) were recorded on a Nermag R10-10S through electronic bombardment (ionisation energy 70 eV). Melting points were measured by the use of capillary tube in a Buchi instrument. Acetonitrile (chromasol quality) was stored over 3Å molecular sieves. Elemental analyses were performed by Service of Microanalyses of CNRS (SOLAIZE - France).

b) - Cyclic Voltammetry : The anode was a rotating platinum disc electrode (Tacussel EDI 409-∅ : 2 mm). It was controled by a Tacussel potentiostat IMT1. Peak potentials are given with reference to the Pleskov electrode ($Ag/AgNO_3$ $10^{-2}M$). The concentration of supporting electolyte ($nBu_4N^+ClO_4^-$) and substrat in CH_3CN were 0.1 $M.L^{-1}$ and 10^{-2} $M.L^{-1}$ respectively. Scan rate was 100 $mV.s^{-1}$ and measurements have been taken under a dry nitrogen stream.

c) - Electrolyses : Electrolyses were monitored by analytical TLC using silica gel plates (kieselgel $60F_{254}$-Merck) or by semicapillary GLC using a Varian 3300 chromatograph on a 15mx0.53mm-OV1 column.

Fluorinations : The electrolysis cell, under a dry nitrogen stream, was thermostated at 13°C and equiped with a magnetic stirrer. 5 mmol of substrat, acetonitrile (50 ml) and $Et_3N,3HF$ (10 ml) were added together. Electrodes were not separated. The anode was a grilled platinum cone (25 mm long - diameters : 40 mm at the bottom and 50 mm at the top). Electrolyses were carried out under a controlled potential in a broken waveform : 3s at the working potential and 2s at 0V. Anode potential was controlled by a Tacussel PRT 100V - 1X (100V - 1A) potentiostat which in turn was controlled by a generator of squarred signal Tacussel GSTP. The quantity of electricity consumed was measured by a Tacussel 165-LN integrator. At the end, the solution was poured on to 300 ml of ice cooled H_2O containing 10 ml of ammonia (28 %). After elimination of CH_3CN, under reduced pressure, the resulting aqueous phase was then washed with water until neutral, dried with $MgSO_4$ and concentrated under partial vacuum. The obtained crude product was purified either by chromatography (silica gel Merck 60H - petroleum ether (45-65°)/Et_3N : 97/3 or by medium pressure liquid chromatography (MPLC) on a 10-M20/25 Partisil column (Whatman).

Methoxylations : Electrolyses were performed using previously described instruments according to reference[12]. 5 mmol of substrat were electrolyzed in methanolic solution of $Et_3N,3HF$ (5 ml in 50 ml of CH_3OH). The work-up was similar as previously described.

Acetoxylations : Oxidations were carried out in 1M AcOK/AcOH (50 ml) starting from 5 mmol of substrat. Acetic acid was removed under reduced pressure and the residue was dissolved with 20 ml of H_2O. After extraction twice with 50 ml of CH_2Cl_2, washing until neutral with $NaHCO_3$ solution, the final work-up was then similar as previously described.

II - PREPARATION OF STARTING VINYL SULFIDES

1a was commercialy available by Aldrich. **1b, 1f, 1g** were obtained by neat reaction between thiophenol and the corresponding alkyne[22]. **1c, 1d, 1h** were prepared according to the procedure described by Labiad and Villemin[23]. **1e** was prepared by reaction between thiophenol and 2-bromo methyl cinnamate in DMF[24].

2-(phenylthio) styrene **1b** (E/Z mixture : 90/10) : Cyclic voltammetry : Ep (V) = 1.14 and 1.49. ^1H NMR : 6.46 and 6.56 (d, 0.2H, $^3J_{cis}$=10.8) ; 6.70 and 6.86 (d, 1.8H, $^3J_{trans}$=15.4) ; 7.14-7.54 (m, 10H).

1-(phenylthio)-stilbene **1c** : m.p. : 47-48°C. Cyclic voltammetry : Ep (V) = 1.07. ^1H NMR : 6.88-7.38 (m, 12H) ; 7.58-7.73 (m, 4H).

2-(phenylthio)-2-methyl styrene **1d** : (E/Z mixture : 40/60) : Cyclic Voltammetry : Ep (V) = 1.24 and 1.42. ^{1}H NMR : 2.02 (d, 1.2H, $^4J_{trans}$=1.3) ; 2.12 (d, 1.8H, $^4J_{cis}$=1.3) ; 6.68 (q, 0.6H, $^4J_{cis}$=1.3) ; 6.70 (q, 0.4H, $^4J_{trans}$=1.3) ; 7.10-7.55 (m, 10H).

methyl-2-(phenylthio) cinnamate **1e** : Cyclic voltammetry : Ep (V) = 1.35. ^{1}H NMR : 3.64 (s, 3H) ; 7.11-7.42 (m, 8H) ; 7.85-7.99 (m, 2H) ; 8.13 (s, 1H). ^{13}C NMR : 52.7 (CH_3) ; 125.0 (CH) ; 126.3 (CH) ; 128.2 (C_q) ; 128.3 (CH) ; 129.0 (CH) ; 130.0 (CH) ; 130.8 (CH) ; 134.2 (C_q) ; 135.4 (C_q) ; 146.1 (CH=) ; 166.7 (C=O).

methyl-3-(phenylthio) acrylate **1f** : (E/Z mixture : 30/70) : Cyclic voltammetry : Ep (V) = 1.56. ^{1}H NMR (E) : 3.67 (s, 3H) ; 5.65 (d, 1H, $^3J_{trans}$=15.2) ; 7.32-7.49 (m, 5H) ; 7.78 (d, 1H, $^3J_{trans}$=15.2). ^{1}H NMR (Z) : 3.76 (s, 3H) ; 5.91 (d, 1H, $^3J_{cis}$=10.1) ; 7.26 (d, 1H, $^3J_{cis}$=7.1) ; 7.32-7.49 (m, 5H).

4-(phenylthio)-3-buten-2-one **1g** : (E/Z mixture : 70/30) : Cyclic voltammetry : Ep (V) = 1.43 and 1.79. ^{1}H NMR : 2.13 (d, 2.1H, J=1.4) ; 2.24 (d, 0.9H, J=1.5) ; 5.97 (d, 0.7H, $^3J_{trans}$=15.3) ; 6.37 (d, 0.3H, $^3J_{cis}$=9.6) ; 7.20 (d, 0.3H, $^3J_{cis}$=9.6) ; 7.25-7.43 (m, 5H) ; 7.68 (d, 0.7H, $^3J_{trans}$=15.3).

1-(phenylthio)-cyclohexene **1h** : Cyclic voltammetry : Ep (V) = 1.15 and 1.40. ^{1}H NMR : 1.23-1.93 (m, 4H) ; 1.93-2.40 (m, 4H) ; 6.10 (t, 1H, J=7) ; 7.00-7.73 (m, 5H).

III - OXIDATIONS OF VINYL SULFIDES

A - Methoxylation

- Methoxylation of **1a** : The remaining oil (0.8 g) was purified by column chromatography (Petroleum ether/Et_2O : 95/5) to afford PhSSPh (80 mg) and **2a** (667 mg). **2a** : ^{1}H NMR : 3.36 (s, 3H) ; 3.56 (s, 3H) ; 3.51 (dd, 1H, ^{2}J=10.6, ^{3}J=7.6) ; 3.61 (dd, 1H, ^{2}J=10.6, ^{3}J=4.3) ; 4.75 (dd, ^{3}J=7.6 and 4.3) ; 7.26-7.32 (m, 3H) ; 7.46-7.51 (m, 2H). MS. m/z : 198 ($M^{+\cdot}$, 18), 153 (23), 109 (15), 89 (93), 88 (43), 59 (100), 45 (39), 31 (36), 29 (32). Anal. calcd. for $C_{10}H_{14}O_2S$: C, 60.58 ; H, 7.12 ; S, 16.17. Found : C, 60.88 ; H, 6.96 ; S, 15.81.

- Methoxylation of **1b** : The remaining oil (1.06 g) was purified by column chromatography (Petroleum ether/Et_2O : 98/2) to give PhSSPh (99 mg), **2b** (63 mg) and **3b** (786 mg). **2b** : ^{1}H NMR : 3.25 (s, 3H) ; 3.34 (s, 3H) ; 4.23 (d, 1H, ^{3}J=5.5) ; 4.70 (d, 1H, ^{3}J=5.5) ; 7.20-7.50 (m, 10H). MS. m/z : 274 ($M^{+\cdot}$, 4) ; 165 (21) ; 154 (9) ; 153 (100) ; 121 (13) ; 105 (41) ; 91 (23) ; 77 (10). **3b** : ^{1}H NMR : 3.30 (s, 3H) ; 3.45 (s, 3H) ; 4.35 (d, 1H, ^{3}J=6.2) ; 4.70 (d, 1H, ^{3}J=6.2) ; 7.10-7.35 (m, 10H). ^{13}C NMR : 55.5 (CH_3) ; 55.9 (CH_3) ; 57.3 (CH) ; 107.3 (CH) ; 127.8 (CH) ; 128.1 (CH) ; 128.9 (2CH) ; 129.1 (2CH) ; 129.3 (2CH) ; 129.7 (2CH) ; 133.2 (Cq) ; 139 (Cq). MS. m/z : 274 ($M^{+\cdot}$, 1) ; 165 (1) ; 134 (3) 105 (4) ; 91 (8) ; 77 (3) ; 76 (3) ; 75 (100) ; 47 (11). Anal. calcd. for $C_{16}H_{18}O_2S$: C, 70.07 ; H, 6.57 ; S, 11.68. Found : C, 69.94 ; H, 6.57 ; S, 11.41.

B - Acetoxylation

- Acetoxylation of **1a** : The oily residue (0.85 g) was purified by column chromatography (Petroleum ether/Et_2O : 95/5) to afford PhSSPh (148 mg), the 1-acetoxy-1,2-diphenylthio-ethane (77 mg) and **4a** (494 mg).**4a** : ^{1}H NMR : 2.02 (s, 3H) ; 2.10 (s, 3H) ; 4.15 (dd, 1H, ^{2}J=17.2, ^{3}J=8.6) ; 4.40 (dd, 1H, ^{2}J=17.2, ^{3}J=5.7) ; 6.2 (dd, 1H, ^{3}J=5.7 and 8.6) ; 7.26-7.40 (m, 3H,) ; 7.50-7.70 (m, 2H). MS. m/z : 254 ($M^{+\cdot}$, 45) ; 153 (26) ; 145 (9) ; 110 (21) ; 103 (8) ; 94 (2) ; 77 (2) ; 69 (3) ; 43 (100). Anal. calcd. for $C_{12}H_{14}O_4S$: C, 56.67 ; H, 5.55 ; S, 12.61. Found : C, 56,91 ; H, 5.90 ; S, 12.36.

1-acetoxy-1,2-diphenylthio-ethane : ^{1}H NMR (60 MHz, VARIAN EM 360) : 1.96 (s, 3H) ; 3.23 (d, 2H, J=7) ; 3.68 (t, 1H, J=7) ; 7.12-7.72 (m, 10H).

- Acetoxylation of **1b** : The oily residue (1.31 g) was purified by column chromatography (petroleum ether/Et_2O : 80/20) to give **4b** (330 mg) and **5b** (825 mg). **4b** : ^1H NMR (diastereoisomeric mixture : 70/30) : 1.97 (s, 3H, major) ; 2.04 (s, 3H, minor) ; 2.07 (s, 3H, minor) ; 2.13 (s, 3H, major) ; 6.01 (d, 1H, ^3J=7.1, minor) ; 6.03 (d, 1H, ^3J=5.4, major) ; 6.36 (d, 1H, ^3J=5.4, major) ; 6.37 (d, 1H, ^3J=7.1, minor) ; 7.17 (m, 10H). **5b** : ^1H NMR : 1.90 (s, 6H) ; 4.50 (d, 1H, ^3J=5.7) ; 7.19 (d, 1H, ^3J=5.7) ; 7.20-7.40 (m, 10H). MS. m/z : 330 ($M^{+\cdot}$, 64) ; 270 (8) ; 228 (12) ; 199 (42) ; 119 (15) ; 109 (2) ; 91 (18) ; 43 (100). Anal. calcd. for $C_{18}H_{18}O_4S$: C, 65.43 ; H, 5.49 ; S, 9.71. Found : C, 65.51 ; H, 5.51 ; S, 9.57.

C - Fluorination

- Fluorination of **1a** : after electrolysis at 0.8 V or 1.0 V, followed by a standard work-up, the crude oil (0.8 g) was analyzed by GLC (Tc : 80-120°C) coupled with a mass spectrometer. **6a** exhibited a peak at m/z : 141 ($Ph\text{-}S^+{=}CHF$) corresponding to a loss of CH_2F from the molecular ion.

6a : ^{19}F NMR : -222.0 (m, 1F, $^3J_{FF}$= 23.7) ; -146.5 (m, 1F, $^3J_{FF}$=23.7). MS. m/z : 174 ($M^{+\cdot}$, 100) ; 142 (5) ; 141 (82) ; 110 (21) ; 109 (40) ; 77 (26) ; 69 (14) ; 66 (8).

1-phenylthio-1-fluoro-2-acetamido-ethane **8a** : ^{19}F NMR : -146.5 (m, 1F) ; MS. m/z : 213 ($M^{+\cdot}$, 9) ; 170 ($M^{+\cdot}$ - $COCH_3$, 100) ; 158 (13) ; 141 ($M^{+\cdot}$ - CH_2NHAc, 74) ; 77 (83) ; 51 (28).

- Fluorination of **1b** : The remaining oil (1.15 g) was purified by column chromatography to give PhSSPh (57 mg) and **6b** (923 mg) as a mixture of diastereoisomers : (72/28). The stereoisomers were separated by MPLC using PARTISIL column and petroleum ether-dioxane (97/3) as eluent. **6b** (diast. mixture) : MS. m/z : 250 ($M^{+\cdot}$, 56) ; 141 (100) ; 109 (39) ; 91 (14) ; 77 (37) ; 45 (9). Anal. calcd. for $C_{14}H_{12}F_2S$: C, 67.18 ; H, 4.83 ; S, 12.81. Found : C, 67.81 ; H, 4.83 ; S, 12.52. ^1H NMR (major, 300 MHz) : 5.64 (ddd, 1H, $^2J_{HF}$=52.0 ; $^3J_{HF}$=12.3 ; $^3J_{HH}$=7.5) ; 5.96 (ddd, 1H, $^2J_{HF}$=49.9, $^3J_{HF}$=15.0, $^3J_{HH}$=7.5) ; 7.35-7.45 (m, 10H). ^{19}F NMR (major) : -157.4 (ddd, 1F, $^2J_{HF}$=49.9, $^3J_{HF}$=12.3, $^3J_{FF}$=10.0) ; -179.8 (ddd, 1F, $^2J_{HF}$=52.0, $^3J_{HF}$=15.0, $^3J_{FF}$=10.0). ^1H NMR (minor, 300 MHz) : 5.63 (ddd, 1H, $^2J_{HF}$=52.4, $^3J_{HF}$=12.5, $^3J_{HH}$=4) ; 5.95 (ddd, 1H, $^2J_{HF}$=52.4, $^3J_{HF}$=6.2, $^3J_{HH}$=4.0) ; 7.36-7.50 (m, 10H). ^{19}F NMR (minor) : -158.3 (ddd, 1F, $^2J_{HF}$=52.4, $^3J_{HF}$=12.5, $^3J_{FF}$=7.4) ; -182.2 (ddd, 1F, $^2J_{HF}$=52.4, $^3J_{HF}$=6.2, $^3J_{FF}$=7.4).

- Fluorination of **1c** : After electrolysis of 1.13 g (3.92 mmol) of **1c**, the oily residue (1.3 g) was purified by chromatography to afford PhSSPh (123 mg), **1c** (74 mg), **6c** (452 mg) and **7c** (452 mg). **6c** (diast. mixture : 60/40) : ^1H NMR : 5.52 (dd, 0.6H, $^2J_{HF}$=44.0, $^3J_{HF}$=6.7) ; 5.86 (dd, 0.4H, $^2J_{HF}$=44.7 ; $^3J_{HF}$=17.6) ; 6.90-7.80 (m, 15H). ^{19}F NMR (major) : -138.5 (dd, 1F, $^3J_{FF}$=26.4 ; $^3J_{HF}$=6.7) ; -178.4 (dd, 1F, $^2J_{HF}$=44.0, $^3J_{FF}$=26.1) - (minor) : -142.3 (t, 1F, $^3J_{HF}$=$^3J_{FF}$=17.6) ; -181.7 (dd, 1F, $^2J_{HF}$=44.7, $^3J_{FF}$=17.6). MS. m/z : 326 ($M^{+\cdot}$, 0) ; 306 (87) ; 197 (26) ; 196 (92) ; 185 (40) ; 177 (13) ; 176 (25) ; 170 (18) ; 166 (10) ; 165 (34) ; 152 (10) ; 122 (10) ; 121 (100) ; 77 (23) ; 51 (17). **7c** : ^1H NMR : 4.60 (t, 1H, $^3J_{HF}$=13.4) ; 7.00-7.70 (m, 15H) ^{19}F NMR : -96.7 (d, $^3J_{HF}$=13.4). MS. m/z : 326 ($M^{+\cdot}$, 7) ; 306 ($M^{+\cdot}$-HF, 30) ; 217 (100) ; 199 (36) ; 197 (50) ; 196 (51) ; 185 (16) ; 177 (13) ; 176 (10) ; 166 (16) ; 165 (28) ; 121 (34) ; 109 (16) ; 77 (25) ; 51 (24).

- Fluorination of **1d** : The oily residue (1.02 g) was purified by column chromatography to give **6d** (198 mg) and **7d** (230 mg). **6d** (diast. mixture : 70/30) : ^1H NMR : 1.49 (d, 0.9H, $^3J_{HF}$=21.0) ; 1.52 (d, 2.1H, $^3J_{HF}$=19.0) ; 5.34 (dd, 0.7H, $^2J_{HF}$=42.4, $^3J_{HF}$=8.1) ; 5.57 (dd, 0.3H, $^2J_{HF}$=44.6, $^3J_{HF}$=12.0) ; 7.17-7.66 (m, 10H). ^{19}F NMR : -126.6 (m, 0.3F) ; -127.6 (m, 0.7F) ; -181.6 (dd, 0.7F, $^3J_{FF}$=18.7, $^2J_{HF}$=42.4) ; -183.3 (dd, 0.3F, $^3J_{FF}$=19.2, $^2J_{HF}$=44.6). MS. m/z : 264 ($M^{+\cdot}$, 0) ; 244 ($M^{+\cdot}$-HF, 74) ; 135 (100) ; 109 (25) ; 91 (72). **7d** : ^1H NMR : 1.66 (t, 3H, $^3J_{HF}$=18.4) ; 4.37 (dd, 1H, $^3J_{HF}$=12.2, $^3J_{HF}$=13.9) ; 7.06-7.58 (m, 10H). ^{19}F NMR : -90.1 (dqd, 1F,$^2J_{FF}$=241.6, $^3J_{CH_3\text{-}F}$=18.3 ; $^3J_{HF}$=12.2) ; -92.2 (dqd, 1F,$^2J_{FF}$=241.6, $^3J_{CH3\text{-}F}$=18.5, $^3J_{HF}$=13.7). MS. m/z : 264 ($M^{+\cdot}$, 66) ; 199

($M^{+\cdot}$-CH_3CF_2, 100) ; 155 (82) ; 127 (72) ; 115 (22) ; 109 (43) ; 105 (23) ; 91 (46) ; 77 (45) ; 65 (19).

- Fluorination of **1e** : After electrolysis, the remaining oil (2.01 g) was analyzed by GLC coupled with a mass spectrometer and by ^{19}F NMR. 0.69 g of crude product was purified by column chromatography to afford 0.40 g (75 % yield) of **6e** as a stereoisomeric mixture (68/32) which has been separated by MPCL. **6e** (major) : ^1H NMR : 3.49 (s, 3H) ; 6.04 (dd, 1H) ; $^2J_{HF}$=45.0, $^3J_{HF}$=19.1) ; 7.25-7.55 (m, 10H). ^{13}C NMR : 53.1 (s, CH_3) ; 93.5 (dd, CH, $^1J_{CF}$=186.8, $^2J_{CF}$=20.9) ; 105.3 (dd, Cq, $^1J_{CF}$=248.4, $^2J_{CF}$=25.2) ; 127.5 (d, Cq, J_{CF}=1.4) ; 128.4 (d, CH, J_{CF}=1.4) ; 128.5 (s, 2CH) ; 129.2 (s, 2CH) ; 130.3 (d, 1CH, J_{CF}=1.8) ; 130.4 (s, 2CH) ; 132.3 (d, Cq, $^2J_{CF}$=20.9) ; 136.2 (d, 2CH, J_{CF}=1.3) ; 165.7 (dd, $^2J_{CF}$=31.4, $^3J_{CF}$=2.0). ^{19}F NMR : -153.5 (t, 1F, $^3J_{FF}$=$^3J_{HF}$=19.1) ; -173.6 (dd, 1F, $^2J_{HF}$=45.0, $^3J_{FF}$=19.1). MS. m/z : 308 (M^+, 3) ; 199 (49) ; 167 (35) ; 139 (18) ; 110 (11) ; 109 (15) ; 77 (25) ; 65 (25) ; 59 (29) ; 51 (29) ; 39 (22). **6e** (minor) : ^1H NMR : 3.31 (s, 3H) ; 6.06 (dd, 1H, $^2J_{HF}$=44.0, $^3J_{HF}$=19.0) ; 7.25-7.55 (m, 10H). ^{19}F NMR : -149.7 (t, 1F, $^3J_{FF}$=$^3J_{HF}$=19.0) ; -187.8 (dd, 1F, $^2J_{HF}$=44.0, $^3J_{FF}$=19.0). MS : identical to **6e** (major).

- Fluorination of **1f** : After electrolysis of 1.5 g (7.7 mmol), the oily residue (1.8 g) was purified by column chromatography to afford unconverted **1f** (135 mg) and **6f** (1404 mg) as a diastereoisomeric mixture (59/41). The stereoisomers were then separated by MPLC using PARTISIL column and petroleum ether/Et_2O (95/5) as eluent. **6f** (diast. mixture) : MS. m/z : 232 ($M^{+\cdot}$, 89) ; 212 (12) ; 192 (12) ; 181 (13) ; 141 (100) ; 109 (80) ; 91 (7) ; 77 (30) ; 69 (13) ; 65 (41) ; 59 (48) ; 51 (26) ; 45 (14). Anal. calcd. for $C_{10}H_{10}O_2F_2S$: C, 51.71 ; H, 4.35 ; F, 16.36 ; S, 13.81. Found : C, 52.21 ; H, 4.47 ; F, 16.41 ; S, 13.80. ^1H NMR (major, 300 MHz) ; 3.88 (s, 3H) ; 5.25 (ddd, 1H, $^2J_{HF}$=48.2, $^3J_{HF}$=10.9, $^3J_{HH}$=3.1) ; 6.08 (ddd, 1H, $^2J_{HF}$=51.0, $^3J_{HF}$=20.8, $^3J_{HH}$=3.1) ; 7.35-7.38 (m, 3H) ; 7.51-7.54 (m, 2H). ^{19}F NMR (major) : -156.9 (ddd, 1F, $^2J_{HF}$=48.2, $^3J_{HF}$=20.8, $^3J_{FF}$=20.4) ; -197.9 (ddd, 1F, $^2J_{HF}$=51.0, $^3J_{HF}$=10.9, $^3J_{FF}$=20.4). ^1H NMR (minor, 300 MHz) : 3.86 (s, 3H) ; 5.17 (ddd, 1H, $^2J_{HF}$=47.1, $^3J_{HF}$=21.0, $^3J_{HH}$=3.2) ; 6.09 (ddd, 1H, $^2J_{HF}$=52.0, $^3J_{HF}$=22.5, $^3J_{HH}$=3.2) ; 7.35-7.39 (m, 3H) ; 7.51-7.56 (m, 2H). ^{19}F NMR (minor) : -162.3 (ddd, 1F, $^2J_{HF}$=47.1, $^3J_{HF}$=22.5, $^3J_{FF}$=18.2) ; -200.9 (ddd, 1F, $^2J_{HF}$=52.0, $^3J_{HF}$=21.0, $^3J_{FF}$=18.2).

- Fluorination of **1g** : After electrolysis of 1.1 g (6.18 mmol) of **1g**, the remaining oil (938 mg) was analyzed by GLC coupled with a mass spectrometer and by ^{19}F NMR. **6g** was detected as a mixture of diastereoisomers (70/30). **6g** (major) : ^{19}F NMR : -163.3 (ddd, 1F, $^2J_{HF}$=52.4, $^3J_{HF}$=24.6, $^3J_{FF}$=18.3) ; -201.5 (dt, $^2J_{HF}$=44.6 ; $^3J_{HF}$=$^3J_{FF}$=22.8). MS. m/z : 216 ($M^{+\cdot}$, 16) ; 196 (3) ; 154 (3) ; 153 (3) ; 141 (3) ; 110 (9) ; 109 (7) ; 77 (6) ; 69 (4) ; 65 (10) ; 51 (8) ; 50 (3) ; 45 (4) ; 43 (100) ; 39 (8). **6g** (minor) : ^{19}F NMR : -156.1 (ddd, 1F, $^2J_{HF}$=53.1, $^3J_{HF}$=12.4, $^3J_{FF}$=18.5) ; -196.6 (dt, $^2J_{HF}$=49.5, $^3J_{HF}$=$^3J_{FF}$=22.3). MS. m/z : 216 ($M^{+\cdot}$, 20) ; 196 (3) ; 181 (3) ; 154 (4) ; 153 (5) ; 141 (3) ; 110 (10) ; 109 (7) ; 77 (6) ; 69 (4) ; 65 (11) ; 51 (9) ; 50 (3) ; 45 (5) ; 43 (100) ; 39 (9). Purification by column chromatography (petroleum ether-Et_3N 97/3) from 867 mg afforded **8g** (473 mg, 42 %) as stereoisomeric mixture (E/Z : 11/89) and unconverted **1g** (168 mg). **8g** (Z) : ^1H NMR : 2.30 (d, 3H, $^4J_{HF}$=3.3) ; 7.17 (d, 1H, $^3J_{HF}$=32.6) ; 7.34-7.51 (m, 5H). ^{19}F NMR : -122.0 (d, 1F, $^3J_{HF}$=32.1). MS. m/z : 196 ($M^{+\cdot}$, 45) ; 161 (6) ; 153 (25) ; 133 (5) ; 109 (19) ; 89 (5) ; 77 (9) ; 69 (7) ; 65 (17) ; 51 (23) ; 50 (8) ; 45 (8) ; 43 (100) ; 39 (13). **8g** (E) : ^1H NMR : 2.34 (d, 3H, $^4J_{HF}$=4.1) ; 6.85 (d, 1H, $^3J_{HF}$=16.0) ; 7.34-7.51 (m, 5H). ^{19}F NMR : -125.4 (d, $^3J_{HF}$=15.6).

- Fluorination of **1h** : After electrolysis of 1.05 g (5.5 mmol) of **1h**, the crude oil (1.14 g) was analyzed by GLC coupled with a mass spectrometer and by ^{19}F NMR. **6h** was detected as a mixture of diastereoisomers (50/50).

$6h_1$: ^{19}F NMR : -128.3 (m, 1F, $^3J_{FF}$=20.7) ; -185.3 (m, 1F, $^3J_{FF}$=20.7). MS. m/z : 228 ($M^{+\cdot}$, 9) ; 189 (16) ; 188 (100) ; 187 (24) ; 173 (19) ; 155 (27) ; 111 (36) ; 110 (56) ; 109 (27) ; 84 (18) ; 79 (61) ; 78 (29) ; 77 (97) ; 69 (16) ; 66 (14) ; 65 (25) ; 53 (17) ; 52 (12) ; 51 (48). **$6h_2$** : ^{19}F NMR : -

133.9 (m, 1F) ; -190.2 (m, 1F). MS. m/z : 228 ($M^{+\cdot}$, 23) ; 208 (9) ; 110 (100) ; 109 (11) ; 99 (11) ; 79 (12) ; 77 (23) ; 65 (11) ; 51 (15). Purification by column chromatography from 800 mg afforded 188 mg of **6h$_2$** as a pure product and 251 mg of α fluoro cyclohexanone[20]. **6h$_2$** : ^{1}H NMR : 1.38-2.11 (m, 8H) ; 4.56 (dm, 1H, $^2J_{HF}$=48.7) ; 7.21-7.66 (m, 5H).

- Trifluorination of **1b** : After the difluorination step (1.0V, 2.5F.Mol.$^{-1}$) the potential was raised up (1.6V) and oxidation was continued until 4.8F.Mol.$^{-1}$ had been passed. The oily residue (1.3 g) was purified by chromatography to afford **9b** (768 mg, 57 % yield) and unconverted **6b** (368 mg, 29 % yield).

9b : ^{1}H NMR : 5.80 (ddd, 1H, $^2J_{HF}$=47.5, $^3J_{HF}$=12.0, $^3J_{HF}$=6.5) ; 7.50-7.90 (m, 10H). ^{19}F NMR : -83.3 (ddd, 1F, $^2J_{FF}$=217.6, $^3J_{FF}$=19.4, $^3J_{HF}$=6.5) ; -86.7 (ddd, 1F, $^2J_{FF}$=217.6, $^3J_{FF}$=18.4, $^3J_{HF}$=12.0) ; -186.5 (ddd, 1F, $^2J_{HF}$=47.5, $^3J_{FF}$=19.4, $^3J_{FF}$=18.4). MS. m/z : 268 ($M^{+\cdot}$, 66) ; 159 (100) ; 109 (87) ; 7 (35) ; 65 (12).

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