論文6. A New Route to Perfluoro(alkoxyalkanoyl) Fluorides from Non-fluorinated Compounds

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A new synthetic procedure for the preparation of perfluoro(alkoxyalkanoyl) fluorides, which are precursors to perfluorinated vinyl ether monomers, from non-fluorinated alkoxyalcohols has been developed. Available perfluoro (alkoxyalkanoyl) fluorides such as perfluoro(2-propoxypropionyl) fluoride, so called HFPO dimer, can be multiplied by the use of the hydrocarbon counterpart alcohols and fluorine gas as raw materials. In the case that the desired perfluoro (alkoxyalkanoyl) fluoride is not readily available, it can be obtained from its hydrocarbon counterpart alcohol and an available perfluoroacyl fluoride.

目次

1.Introduction

Alkoxyalkanoyl fluorides are important intermediates for fluororesins, such as PFA (perfluoroalkoxy copolymer). PFA is one of the most important perfluorinated polymers that is used as both thermally and chemically resistant material with melt processibility for industrial purpose. One of its monomers, perfluoro(propyl vinyl ether) (PPVE), has been prepared via dimerization of hexafluoropropylene oxide (HFPO) (**Scheme 1**). Although the HFPO chemistry is well-established, it is specific to the propoxyl group as the side chain in the polymer in this case, because HFPO itself is employed as the precursor of the perfluoroalkoxide to react with HFPO. In the case of the perfluoro(alkyl vinyl ethers) other than PPVE, it is costly, because the preparation of the precursor perfluoroalkoxides is not easy.

Recent perfluorinated hypofluorite chemistry and the fluorination method of partially-fluorinated 1,2-dichloroethyl ethers can give perfluoro(alkyl vinyl ethers) other than PPVE. However, these methods are still costly, because they require expensive (per) fluorinated starting materials. Herein we present an essentially different synthesis. Our new synthetic route starts from non-fluorinated counterparts and utilizes liquid-phase direct fluorination as a key step. Although Lagow et al. reported liquid-phase direct fluorination of non-fluorinated compounds, they just adopted it to molecules with simple structure, such as octyl octanoate. We considered that it could be applied to the synthesis of industrially important compounds, such as perfluorinated alkyl vinyl ethers, if we could make the corresponding hydrocarbon counterparts.

▲Page Top

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2. Results and discussion

2・1. Synthesis of the precursors to PPVE

We chose PPVE as our first target molecule, because it has a relatively simple structure. PPVE can be made either by thermal elimination of perfluoro (2-propoxypropionyl) fluoride (1) or by dechlorination of perfluoro(1,2-dichloroethyl propyl ether) (2).The dichloroether (2) could be obtained by direct fluorination of the corresponding hydrocarbon l,2-

dichloroethyl propyl ether (3), which is obtained from inexpensive propyl vinyl ether in only one step. Because it seemed relatively easy, this route was selected as our first trial.

The dichloroethyl ether (3) was unstable, and it was difficult to purify by distillation or even by chromatography. Therefore, the direct fluorination without purification of the substrate was carried out, basically applying Lagow's method. The direct fluorination was conducted with 20% fluorine gas diluted in nitrogen gas, and proceeded as we had intended (Scheme 2). However, it was limited by migration of chlorine atoms and formation of considerable amounts of by-products arising from C-C and C-O bond cleavage. The cause of this was probably some reaction in the vapor phase, due to high volatility of the substrate, and the yield was only 40% at best.

This suggested that compounds with low volatility are desirable for the liquid-phase reaction.

Then we examined the synthesis of the perfluoroacyl fluoride **1**. This compound could be derived from alkoxyalcohol **4** as the precursor, however, direct fluorination of it seemed to be dangerous, because formation of unstable hypofluorite would likely to occur first. As a result, protection of the OH group was essential in this route. The protecting group, in this case, should be a perfluorinated group for inactivity against fluorination, of large molecular weight for low volatility and removable after fluorination. Considering these demands, $-COCF(CF_3)OCF_2CF_2CF_3$ seemed to be most attractive, because the corresponding acyl fluoride is available as the intermediate to PPVE in the conventional manufacturing process, and it could give the same acyl fluoride from perfluorinated hydrocarbon moiety, after addition of fluoride ion followed by elimination.

The actual synthesis was carried out as follows. The starting non-fluorinated alcohol **4** was synthesized from inexpensive propylene oxide and 1-propanol in the presence of an acid catalyst in one step.Esterification (Scheme 3) was carried out simply by mixing the non-fluorinated alcohol **4** and the perfluoroacyl fluoride **1** from the conventional manufacturing route, with removal of HF formed during the reaction in a stream of nitrogen, to give the partially-fluorinated ester 5 in 99% yield.

The next liquid-phase direct fluorination was carried out basically in manner similar to Prof. Lagow's method (Scheme 4). Cooling was required in order to control the reaction together with use of an inert solvent, and appropriate dilution of both fluorine and the substrate. However, an excess of fluorine to replace all of the hydrogen atoms in the substrate was essential at all times as in the case of the non-fiuorinated substrates that are described in the literature. In our method, however, a potentially dangerous vapor-phase reaction was avoided by employing a higher-molecular weight partially-fluorinated ester as the substrate. A further benefit is that the solubility of the substrate in the perfluorinated solvent increased. This is in contrast to that of a non-fluorinated compound. Moreover, it was found that the starting acyl fluoride itself is a good solvent for this fluorination.Thus, the direct fluorination of the partially-fluorinated ester 5 was carried out with 1.5-3.0 equivalent of fluorine diluted to 20-50% in nitrogen to give the desired perfluoroester **6** in over 90% yield. In the case that conversion was not enough, addition of benzene was effective in order to initiate the formation of fluorine atoms, as reactive species, to complete the fluorination process.

The perfluorinated ester **6** obtained was converted to the desired acyl fluoride **1** with 20 mol% of sodium fluoride as a catalyst (Scheme 5). This thermal elimination reaction gave 2 moles of the desired acyl fluoride in 94% yield at lower temperature, compared to the reaction without catalyst.

The total process to a perfluorinated vinyl ether is shown in Scheme 6. We named this process "PERFECT" that is the abbreviation of PERF luorination of an Esterified Compound then Thermal elimination. For the case of the synthesis of PPVE, the overall yield of the acyl fluoride **1a** from the one we started with was 180% per cycle. By repeating the cycle, the acyl fluoride **1a** will increase in geometric progression. In this sense, the cycle is a multiplication of the acyl fluoride.

2・2. Synthesis of various perfluoro (alkoxyalkanoyl) fluorides

In cases where the desired perfluoroacyl fluoride is available, it can be multiplied by the method shown above, but in many cases, the desired acyl fluorides are not readily available. In such situations, the hydrocarbon counterpart alcohol **4a** with the structure corresponding to the desired acyl fluoride **1a** is reacted with an available acyl fluoride **1b** (Scheme 7). The resulting mixed ester **5ab** is fluorinated to give the perfluoroester **6ab**, and the following thermal elimination gives the desired acyl fluoride **1a** and the recovered starting one **1b**. Once the desired acyl fluoride **1a** is obtained, then it can be multiplied by synthesizing the homo ester **5aa**, applying the PERFECT process. Thus, liquid-phase direct fluorination followed by thermal elimination gives 2 mols of the desired acyl fluoride **1a**.

According to this methodology, various perfluoroacyl fluorjdes can be synthesized. The results will be reported separately.

▲Page Top

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3. Conclusions

The synthetic method of perfluoro(alkoxyalkanoyl) fluorides utilizing liquid-phase direct fluorination with elemental fluorine was investigated. Direct fluorination of a partially-fluorinated ester synthe-sized from a non-fluorinated alkoxyalcohol and perfluorinated acid fluoride (1) was achieved in high yield. Degradation of the resulting perfluoroester gave the desired acid fluoride. It has advantages over known direct fluorination ethods as follows.

1. It avoids vapor-phase reaction by employing a substrate with low vapor pressure.
2. It significantly increases the solubility of the substrate in the perfluorinated solvent used for fluorination, compared to non-fluorinated ester.
3. It is easy to synthesize the partially-fluorinated substrate because perfluorinated acyl fluoride (1) is available.
4. Various perfluoroacyl fluorides can be synthesized, because its carbon backbone is synthesized in hydrocarbon compounds by ordinary organic synthesis.

The raw materials are inexpensive hydrocarbon compounds and fluorine gas. Therefore, this method is expected to provide useful perfluorinated compounds in reasonable price.

▲Page Top

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4. Experimental

General Remarks: NMR spectra were obtained on a JEOL EX-400 or alpha; -600 (tetramethylsilane as internal standard for ^{1}H, trichlorofluoromethane for ^{19}F, and $CDCl_3$ for ^{13}C). High resolution mass spectra were obtained on JEOL SX-102A coupled to HP-5890 with a 60m capillary column J&W DB-1 or DB-1301. *Elemental fluorine was generated by Fluoro Gas Fluorodec 30. Elemental fluorine is highly toxic and corrosive gas, and may cause explosion when it meets organics in the vapor-phase. Extreme care must be taken when handling it! Both the liquid and vapor of hydrogen fluoride (bp. 19.5℃) evolved during the reaction are also highly corrosive and cause severe burns when in contact. Care must be taken! Prior to use, all hydrocarbon greases must be removed and the apparatus must be gradually passivated with elemental fluorine.* Although the use of 1,1, 2-trichlorotrifluoroethane (R113) is regulated, we will mention experimental examples with it for convenience, because it is still much more cheaply available (Aldrich) than compound (1) for use as solvent. Care must be taken in order to avoid discharge to the environment. Once enough of the compound (1) is obtained in the cycle, it should be used instead of R113. Other reagents were obtained from Kanto Chemicals and used without purification.

Perfluoro(1, 2-dichloroethyl propyl ether) (2)

In a 2L autoclave made of hastelloy C, equipped with a condenser maintained at - 10℃ at the gas outlet of the autoclave, a suspension of sodium fluoride (60.0g, 1.43mol) and 1, 1, 2-trichlorotrifluoroethane (1290g) was stirred and maintained at - 10°C. Nitrogen gas was blown into the system for 1.5 hours, and then, fluorine gas diluted to 20% with nitrogen gas, was blown into the mixture for 1 hour at a flow rate of 12.5L/h at atmospheric pressure. While blowing the 20% fluorine/ nitrogen at the same rate, a solution of 1 , 2-dichloroethyl propyl ether (3) (20.0g, 0.127mol) dissolved in l, l, 2-trichlorotrifluoroethane (394g) was injected over a period of 18 hours. Then, while blowing the 20% fluorine/nitrogen at the same rate, a solution of benzene in 1, 1, 2-trichlorotrifluoroethane (0.01g/mL) was injected in an amount of 12mL while raising the temperature from - 1O°C to room temperature. Then, the inlet for benzene injection was closed, and the outlet valve of the autoclave was closed. When the pressure became 0.12MPa, the fluorine gas inlet valve of the autoclave was closed, and stirring was continued for 1 hour. During this time, the pressure dropped slightly. Then the pressure was adjusted to atmospheric pressure, and while maintaining the internal temperature of the reactor at room temperature, another benzene solution (12mL) was injected. The same operation was repeated five times. The total amount of benzene injected was 0.74g. Further nitrogen gas was blown into the mixture for 4.5 hours. Yield was determined by NMR with perfluorobenzene as an internal standard to be 40%.

2-Propoxypropyl perfluoro (2-propoxypropionate) (5)

In a 2L autoclave made of hastelloy C, acyl fluoride (1) (1800g, 5.43mol) was added dropwise to distilled 2-propoxy-1-propanol (620g, 5.25mol) over a period of 8 hours while bubbling nitrogen gas to strip pff hydrogen fluoride evolved, maintaining the internal temperature at from 25 to 35°C. After the addition, stripping off remaining HF and excess acyl fluoride (1) by bubbling nitrogen gas gave partially-fluorinated ester (5) (2245g, 5.22mol, 99.20% yield); bp. 52 to 61°C/ 3.6 to 4.0 kPa; ^{1}H NMR (399.8MHz, $CDCl_3$) δ 0.90 (t, J=7.5Hz, 3H), 1.20 (d, J=5.4Hz, 3H), 1.50 to 1.60 (m, 2H), 3.33 to 3.50 (m, 2H), 3.64 to 3.74 (m, 1H), 4.23 to 4.29 (m, 1H), 4.34 to 4.41(m, 1H); ^{19}F NMR (376.2MHz, $CDCl_3$) -80.9 and -87.4 (2F, AB quartet, J_{FF}= 149Hz), -82.3 (3F), -83.1 (3F), - 130.7 (2F), - 132.7 (lF); High resolution mass spectrum (EI method) 431.0746 (M+H, calculated for $C_{12}H_{14}F_{11}O_4$: 431.0716).

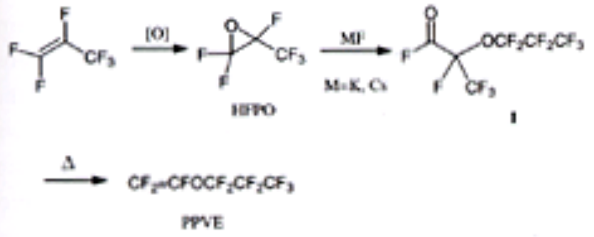
Perfluoro (2-propoxypropyl 2-propoxypropionate) (6)

In a 3L autoclave made of nickel, equipped with a condenser maintained at 20°C, a NaF pellet packed layer and condenser maintained at -10°C in series at the gas outlet of the autoclave, and a liquid return- ing line in order to return the condensed liquid from the condenser maintained at -10°C,1,1,2-trichlorotrifluoroethane (1890g) was stirred and maintained at 25°C. Nitrogen gas was blown into the system for 1.5 hours, and then, fluorine gas diluted to 20% with nitrogen gas was blown into the mixture for 3 hours at a flow rate of 8.91L/h at atmos-pheric pressure. While blowing the 20% fluorine/nitrogen at the same rate, a solution of partially- fluorinated ester (5) (60.0g. 0.139mol) dissolved in 1,1,2-trichlorotrifluoroethane (601g) was injected over a period of 63.7 hours. Then, while blowing the 20% fluorine/nitrogen at the same rate, a solution of benzene in 1,1,2-trichlorotrifluoroethane (0.0lg/mL) was injected in an amount of 18mL while raising the temperature from 25°C to 40°C. Then, the inlet for benzene injection was closed, and the outlet valve of the autoclave was closed. When the pressure became 0.20MPa gauge, the fluorine gas inlet valve of the autoclave was closed, and stirring was continued for I hour. During this time, the pressure dropped slightly. Then the pressure was adjusted to atmospheric pressure, and while maintaining the internal temperature of the reactor at 40°C, another benzene solution (6mL) was injected. The same operation was repeated twice. The total amount of benzene injected was 0.309g. Further nitrogen gas was blown into the mixture for 2.0 hours. Distillation gave the perfluorinated ester (6) (86.0g, 0.129mol, 93.2% yield); bp. 46 to 51°C/5.2kPa; ^{19}F NMR (564.6MHz, $CDCl_3/C_6F_6$) -80.6 (1F), - 80.8 and -80.9 (3F), -81.6 to -83.1 (2F), -82.6 (6F), -82.8 (3F), -86.7 (1F), -87.4 (1F), -87.5 (1F), - 130.6 (4F), - 132.2 (1F), - 145.7 and - 145.9 (1F); ^{13}C NMR (150.8MHz, $CDCl_3/C_6F_6$) 100.26 and 100.28, l02.8, 106.8, 107.0, 116.0, 116.2, 116.5 and ll6.6, 117.4, 117.5, 117.9, 117.9, 152.2 and 152.3; High resolution mass spectrum (CI$^+$) 664.9496 (M + H, calculated for $CI_2HF_{24}O_4$: 664.9492).

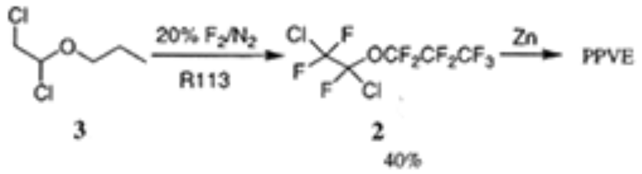
Degradation of perfluorinated ester (6)

In a 100mL flask with reflux condenser adjusted at 70˚C, a suspension of perfluorinated ester (6) (55.3g, 83.2mmol) and a NaF powder (0.70g, 17mmol) was heated at 140˚C for 15 hours in an oil bath with vigorous stirring. A liquid sample (52.1g, 157mmol, 94.2% yield) was recovered through the condenser. It corresponded with the authentic compound (1) both by gas chromatography and NMR.

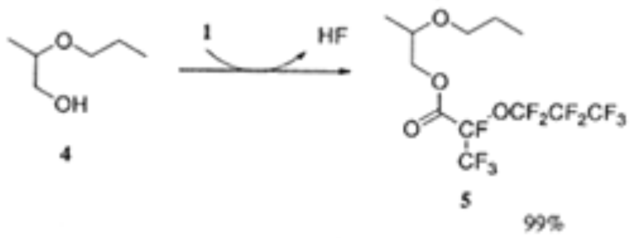
▲Page Top



Scheme 1 Conventional Synthesis of PPVE.



Scheme 2



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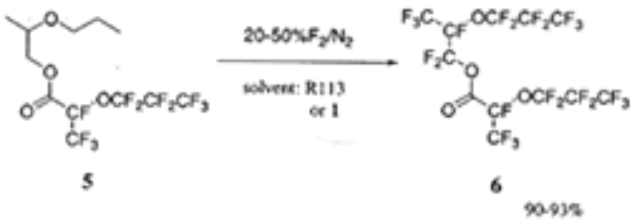

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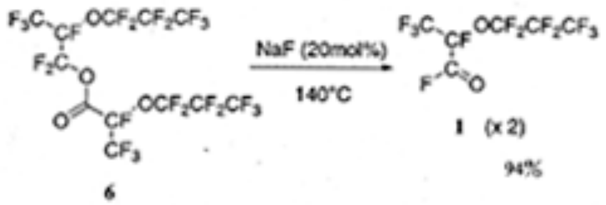

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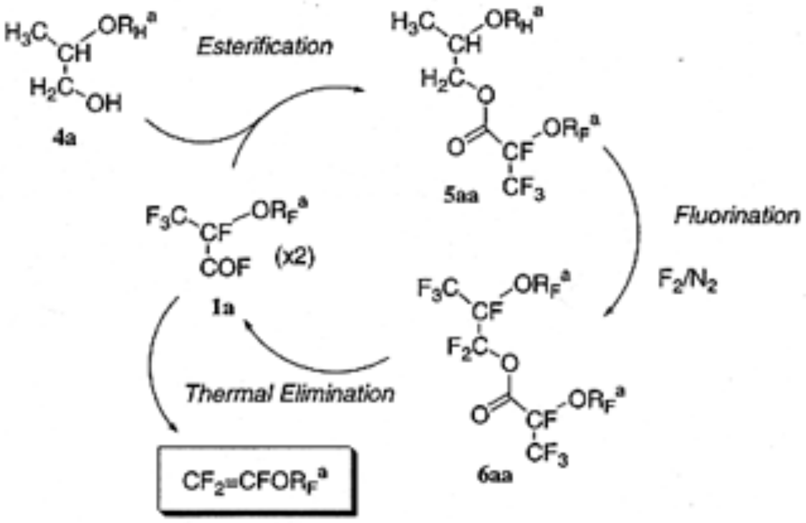
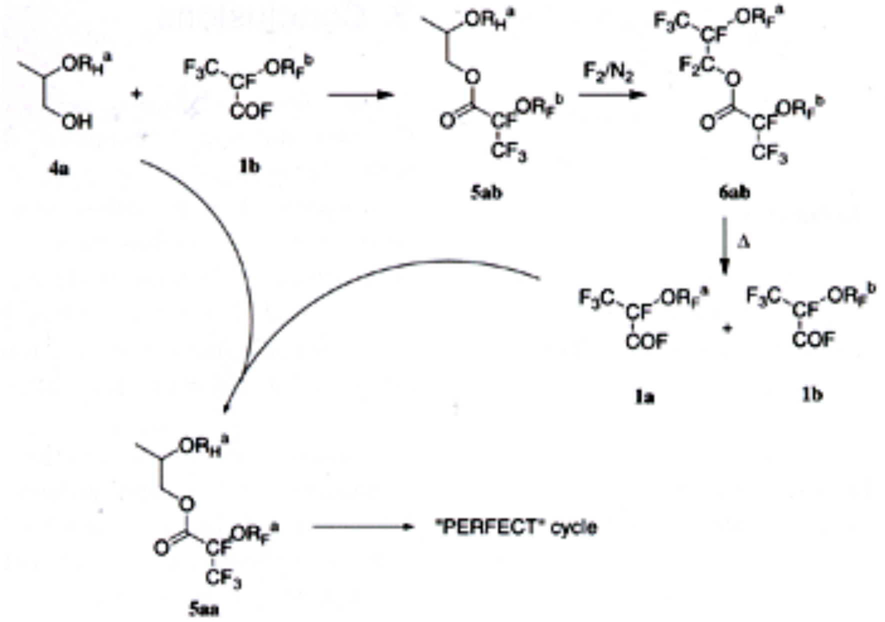


Scheme 6 The “PERFECT” cycle.



Scheme 7