PERKIN 1
COMMUNICATION

Selective reductive defluorination of dicyclohexyl compounds: intramolecular coupling reaction by reductive cleavage of C–F bonds

Kuangsen Sung *[a] **and Richard J. Lagow** *[b]

[a] *Department of Chemistry, Trent University, Peterborough, Ontario, Canada K9J 7B8*
[b] *Department of Chemistry, The University of Texas at Austin, Austin, TX 78712-1167, USA*

Reductive defluorination of perfluoro(dicyclohexyl ether) 1 with benzophenone anion radical in tetrahydrofuran produces perfluoro(dibenzofuran) 2 with a surprising ring-closure, whereas reductive defluorination of perfluoro(dicyclohexyl) 4 under the same conditions gives perfluoro(diphenyl) 6 with no products involving ring-closure.

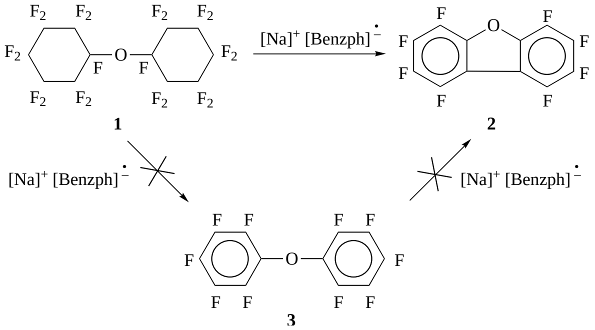
Reductive cleavage of carbon–halogen bonds is an issue of fundamental as well as practical interest in organic and organometallic synthesis.[1] Most of the reductive carbon–halogen bond cleavages involve C–Cl, C–Br and C–I bonds,[2] with few examples of C–F bond cleavage. The C–F bond in saturated fluorocarbons is very strong (*ca.* 552 kJ mol^{-1}),[3] and the saturated fluorocarbons are highly resistant to chemical attack by most reagents. It was reported that Teflon is attacked only at drastic conditions like molten sodium metal at temperatures higher than 200 °C.[4]

Recently, reductive cleavage of C–F bonds has gained attention. Examples include activation of C–F bonds on both sp^2-hybridized carbons[5] and sp^3-hybridized carbons.[6–10] For C–F bonds on saturated carbon, it was reported that the strong reducing agents like alkali metals, alkaline earth metals, and naphthalene anion radical cleave C–F bonds on saturated carbon without selectivity.[6] Selective reductive defluorination of saturated cyclic fluorocarbons to fluoroaromatics was achieved by using iron metal, $CsCoF_4$ and sodium oxalate at high temperature,[7] or using benzophenone anion radical or Na[Cp-Fe(CO)$_2$] at low temperature.[8] Cyclic fluorocarbons with a fluorine atom on tertiary carbon react slowly with sodium benzenethiolate to form completely defluorinated and fluoroaromatic compounds.[9a] Photoinduced catalytic defluorination was also applied to fluorocarbons with a fluorine atom on tertiary carbon.[9b,c,d] Cleavage of C–F bonds on both saturated and unsaturated carbon has been achieved with $(MeC_5H_4)_3U(Bu^t)$,[10a] and metallocene-mediated defluorination converted saturated cyclic fluorocarbons to the corresponding fluoroarenes.[10b,c]

In this communication, we report selective reductive defluorination of saturated perfluorinated dicyclohexyl compounds with benzophenone anion radical in tetrahydrofuran and the first example of intramolecular coupling reaction by reductive cleavage of C–F bonds.

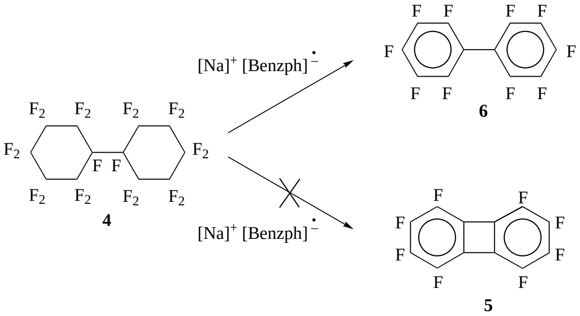
Reductive defluorination of perfluoro(dicyclohexyl ether) **1**[11] with benzophenone anion radical in tetrahydrofuran from −70 to 20 °C produced a fused perfluoroaromatic ether, perfluoro(dibenzofuran) **2** in *ca.* 60% yield. In this reaction, no trace of perfluoro(diphenyl ether) **3** has been found (Scheme 1). The perfluoro(dibenzofuran) **2** was well-characterized by high resolution mass (EI) (for *m*/*e* of $C_{12}F_8O$; Calc. 311.982 14; found 311.983 17), and ^{19}F NMR spectroscopy [−138.0 (2F), −153.7 (2F), −159.4 (2F), 160.7 (2F) ppm in $CDCl_3$], which is consistent with published data.[12a] To our knowledge, this is the first example of intramolecular coupling reaction by reductive cleavage of carbon–fluorine bonds.

The perfluoro(diphenyl ether) **3** was suspected as an intermediate for this reductive defluorination reaction. However, a sample of **3**[13] did not react with benzophenone anion radical in tetrahydrofuran at the same conditions as reductive defluorination of **1**. The result implies that **3** is not an intermediate for the reductive defluorination of perfluoro(dicyclohexyl ether) **1**.



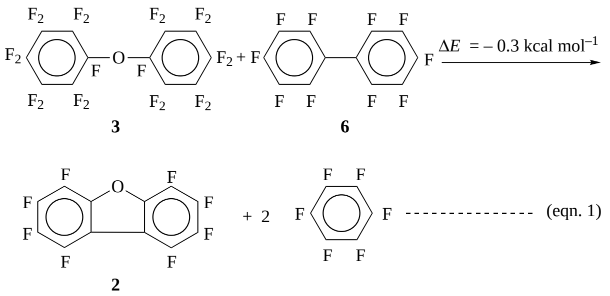
Scheme 1 Reductive defluorination of perfluoro(dicyclohexyl ether) **1**

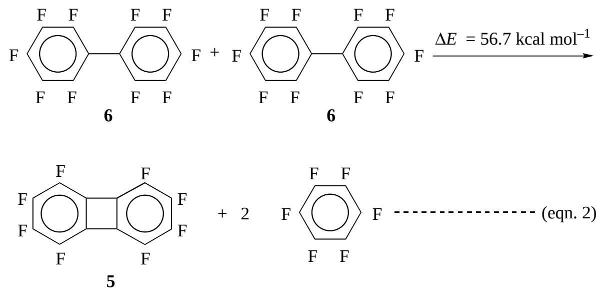
Perfluoro(dibenzofuran) **2**, the reductive defluorination product of **1**, has three fused aromatic rings. The central 5-membered ring has 6π electrons. The aromatic character of the product may provide some stability and a driving force for the reaction from the thermodynamic point of view. To examine the importance of aromaticity in the reaction, perfluoro(dicyclohexyl) **4** was prepared from the corresponding hydrocarbon by liquid-phase direct fluorination[11] and then it was treated with benzophenone anion radical in tetrahydrofuran at the same conditions as reductive defluorination of **1**. Reductive defluorination of **4** did not give a fused perfluoro(biphenylene) **5**,[12b,c,d] but a non-fused perfluoro(diphenyl) **6** with *ca.* 55% yield (Scheme 2). An intramolecular cyclization does not occur in this case. The perfluoro(diphenyl) **6** was well-characterized by high resolution mass (EI) for *m*/*e* of $C_{12}F_{10}$; Calc. 333.984 03, found 333.984 53) and ^{19}F NMR spectroscopy [−137.4 (4F), −150.2 (2F), −160.6 (4F) ppm in $CDCl_3$], which is consistent with published data.[12a,e]



Scheme 2 Reductive defluorination of perfluoro(dicyclohexyl) **4**

Semiempirical calculations have been done at a level of AM1[14] on structures of **2**, **3**, **5**, **6** and perfluorobenzene. Compounds **2**, **5** and perfluorobenzene are planar, while compounds **3** and **6** are twisted structures with dihedral angles 25.6° and 89.9°, respectively (Fig. 1). Their electronic energies corrected with scaled zero-point vibrational energies (scale factor = 0.8929)[15] were used for isodesmic reactions (eqns. 1 and 2). To predict aromatic stability caused by ring-closure of **3** to **2**, the isodesmic reaction (eqn. 1) was designed with equivalent





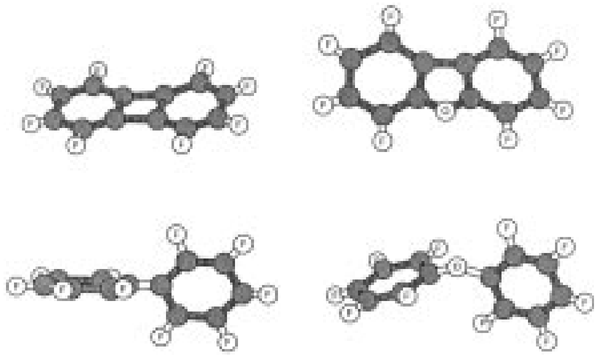


Fig. 1 Optimized structures of perfluoro(dibenzofuran) **2**, perfluoro(diphenyl ether) **3**, perfluoro(biphenylene) **5**, and perfluoro(diphenyl) **6** at the level of AM1

bonds on both sides of the reaction. The reaction is exothermic with $\Delta E = -0.3$ kcal mol^{-1} and this implies that the ring-closure does give a small amount of aromatic stability. The same method was applied to ring-closure of **5** to **6**. As expected, the isodesmic reaction (eqn. 2) is endothermic with $\Delta E = 56.7$ kcal mol^{-1}. The ring-closure of **5** to **6** would bring antiaromatic character in the central ring of **6** or along the periphery of the whole fused molecule, which is the source of instability.

In addition to aromatic stabilization, flexibility of the ether linkage and a suitable reducing potential of **1** are possible driving forces for the reductive defluorination of **1** to **2** with a special ring closure.

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