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## **Accepted Article** Title: The unusual fusion of α-fluorinated benzophenones under McMurry reaction conditions Authors: Vladimir Akhmetov, Mikhail Feofanov, Vitaliy loutsi, Frank Hampel, and Konstantin Y Amsharov This manuscript has been accepted after peer review and appears as an Accepted Article online prior to editing, proofing, and formal publication of the final Version of Record (VoR). This work is currently citable by using the Digital Object Identifier (DOI) given below. The VoR will be published online in Early View as soon as possible and may be different to this Accepted Article as a result of editing. Readers should obtain the VoR from the journal website shown below when it is published to ensure accuracy of information. The authors are responsible for the content of this Accepted Article. To be cited as: Chem. Eur. J. 10.1002/chem.201805290 Link to VoR: http://dx.doi.org/10.1002/chem.201805290 **Supported by** ACES

## The unusual fusion of α–fluorinated benzophenones under McMurry reaction conditions

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Abstract: By exposing of  $\alpha$ -fluorinated benzophenones to McMurry reaction conditions, we have observed remarkable formation of 9,10diphenylanthracene's derivatives. This unexpected transformation necessitates the cleavage of the exceptionally stable aromatic C-F bond under mild McMurry conditions. In this work we have investigated the condensation of several related fluorinated benzoand acetophenones, which allow us to propose the domino-like fusion mechanism for this unusual transformation. The scope and limitation of the fluorine-promoted benzophenone fusion is discussed.

#### Introduction

Fluoroorganic chemistry remains to be poorly investigated field due to often misleading assumption of the bond stability and thus its inertness. Nevertheless, there are some pioneering works in the field showing applicability of the C-F bond for organic synthesis<sup>[1]</sup> e.g. for Aryl-Aryl coupling.<sup>[2]</sup> Moreover, some methods allow the synthesis of highly interesting strained polycyclic aromatic hydrocarbons (PAHs) with a curved surface, known as geodesic polyarenes,<sup>[3-5]</sup> which remain to be hardly available since there are only a few synthetic approaches enabling their preparative synthesis.<sup>[6]</sup>



Scheme 1. Three step synthetic approach to (4) from commercially available 2,6-difluoro-benzophenone.

Addressing the issue we have suggested a possible pathway enabling facile three-step synthesis of diindeno[1,2,3,4defg:1',2',3',4'-mnop]chrysene (4) which may serve as an example of the important representative of geodesic polyarenes.<sup>[7]</sup> Leaving aside the final outcome of our efforts to synthesize (4) here we describe rather unexpected reaction observed during the implementation of the first step corresponding to the transformation of (1) to (2). The required precursor (2) can be obtained by standard McMurry coupling of

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the respective fluorinated benzophenone (1). McMurry reaction is well known for its high functional group tolerance and appears as a well-established synthetic approach to various alkenes using carbonyl compounds as reactants.<sup>[8]</sup> The reaction is also suitable for the preparation of highly substituted phenylethanes.<sup>[9]</sup> Surprisingly, beside the expected product we observed the formation non-symmetrical fluorinated 9,10of diphenylanthracene (5). Due to the idiosyncrasy of the structure it is virtually impossible to synthesize such a derivative via known conventional methods.<sup>[10]</sup> Even though the obtained molecule is interesting itself as a precursor to non-IPR fullerenes' fragment<sup>[11]</sup>, it is even more important to consider this side product as a harbinger of a great potential of the C-F bond and its exploitation under various conditions.

#### **Results and Discussion**

The 2,6-difluoro-benzophenone (1) was chosen for the synthesis of target diindenochrysene (4) in accordance with Scheme 1. As a first step fluorinated benzophenone was subjected to standard McMurry conditions. Analysis of the reactionary mixture revealed the formation of the two diastereomers of the desired product (2) with 50% yield and the presence of an unexpected side product, which turned out to have a UV-vis spectrum corresponding to anthracene's core. The product was isolated and investigated by means of NMR and X-ray diffraction analysis, which revealed that the molecular structure of the isolated substance corresponds to 10-(2,6-difluorophenyl)-1-fluoro-9-phenylanthracene (5).



**Figure 1.** The implementation of the first step of the synthesis. The benzophenone molecules participating in the fusion are highlighted by different colors. (inset) ORTEP plot of (5) in the crystal. Thermal ellipsoids are drawn at the 50% probability level (only one orientation of 5 in the crystal is shown for clarity).

The yield of anthracene (5) was found to be 35%. Among major (2) and (5) only trace amounts of several unidentified byproducts were detected according HPLC analysis. In order to investigate whether this reaction is applicable for different related substrates a set of reactions with various  $\alpha$ -fluorinated aceto- and benzophenone derivatives were carried out (Scheme 2). As a matter of fact, only in case of  $\alpha$ -fluorinated benzophenone the

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formation of 9,10-diphenylanthracene core (7) was observed along the formation of the expected tetraphenylethane (6). However, exposing 2,2'-difluorobenzophenone to the reactionary conditions has led to the isolation of (8) as a single major product with the moderate yields.



Scheme 2. Transformations of various  $\alpha$ -fluorinated phenylcarbonyl compounds under McMurry reaction conditions.

In the case of 2-fluoroacetophenone and 2-fluorobezaldehyde no anthracene formation was detected and only expected McMurry products were isolated. Two isomers of (10) and only E-isomer (12) respectively. Additionally, we attempted to investigate whether perfluoro aromatic compounds show the formation of the corresponding anthracene derivatives. For this purpose we 2,3,4,5,6-tetrafluorobezophenone subjected to McMurry conditions and obtained a complicated mixture which did not contain any major product that could be isolated. Moreover, we did not observe any products that would have UV-vis spectrum corresponding to an anthracene derivative. This evidence shows that the activation of C-F bonds in such case is not selective and leads to a huge number of possible reaction pathways.

Due to heterogeneous nature of the McMurry reaction the investigation of the reaction mechanism appears to be difficult. However, on the basis of the common knowledge the following mechanism can be proposed (Scheme 3). As a first step a set of single-electron transfers from reduced titanium particles to the carbonyl group of the reactant takes place. Generated anion then

attack activated  $\pi$ -system of the fluoroarene leading to the aromatic nucleophilic substitution of fluoride. The substitution is facilitated by the presence of the electron withdrawing groups. The next step according to our experimental observation most probably includes electrophilic aromatic substitution, since the presence of the electron-withdrawing groups in the attacked phenyl ring tends to prevent the further formation of the anthracene's cores as it was observed in cases of (9), (11) and (13). This step can be induced by polarization of carbonyl group by Lewis acids such as Ti<sup>3+</sup> and Zn<sup>2+</sup> containing species. Another strong evidence for the cationic nature of the last step is the formation of (7) without the second possible isomer containing fluorine atom within anthracene fragment, which was confirmed by means of X-Ray diffraction analysis (see SI).



Scheme 3. Suggested mechanism of the transformation of 2,6-difluorobenzophenone under McMurry reaction conditions.

Considering the proposed mechanism it is reasonable to assume that the yields and selectivity of the reaction might be increased via introduction of additional electron-withdrawing groups to the fluorinated rings of benzophenone and electron donating groups to opposite one, thus facilitating both steps, initial nucleophilic attack of C-F bond and consequent electrophilic substitution.

In order to estimate and compare kinetic barriers of the nucleophilic attacks by carbonyl anion leading to either McMurry products or anthracene based compounds we carried out model DFT calculations on PBE/TZ2p level. In the model the titanium particle was replaced with a hydrogen atom for simplicity reason.<sup>[12]</sup>

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Figure 2. Schematic representation of the DFT data on the competition between two nucleophilic attacks.

The obtained energies (Figure 2) are going in line with the observed experimental data showing lower barriers for nucleophilic attack of carbonyl group and 2-3 times higher, although still reasonable values for the attack of fluorinated carbon.

#### **Experimental Section**

**Supporting Information** (see footnote on the first page of this article): Experimental procedures, and compound characterization data (<sup>1</sup>H NMR; <sup>13</sup>C NMR; UV-vis; X-Ray diffraction data). This material is available free of charge in the Supporting Information.

#### Conclusions

Since C-F bond is considered to be one of the most stable bonds in organic chemistry, it is commonly assumed that it difficult to be exploited in organic synthesis due to being inert. However, there are quite a few evidences revealed during recent years, which refute this fallacy. Discovered reaction proves that fluoroorganic chemistry still remains to be undeveloped and extremely promising field. Moreover, the transformation seems to be quite attractive tool enabling synthesis of fluorinated 9,10diphenylanthracenes not available otherwise.

#### **Conflicts of Interest**

The authors declare no conflict of interest.

CCDC-1867159-1867160 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via <u>www.ccdc.cam.ac.uk/data\_request/cif</u>.

#### Acknowledgments

The authors thank the Deutsche Forschungsgemeinschaft (DFG-SFB 953 "Synthetic Carbon Allotropes" - Projects A6, AM-407). We also thank Olga Mazaleva for the help wih carrying out DFT calculations.

Keywords: McMurry reaction • Anthracene • C-F chemistry

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#### Entry for the Table of Contents (Please choose one layout)

Layout 1:

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It was found that α-fluorinated benzophenones undergo unusual fusion under standard McMurry conditions (see figure) leading to the formation anthracene derivatives which necessitates the cleavage of the exceptionally stable aromatic C-F bond. Discovered reaction proves that fluoroorganic chemistry still remains to be undeveloped and extremely promising field.



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