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$Rh_2(OAc)_4$-catalyzed formation of *trans*-alkenes from the reaction of aldehydes with perfluorophenyl diazomethane through tellurium ylide

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Abstract—$Rh_2(OAc)_4$ can catalyze the formation of perfluorophenyl-containing *trans*-epoxides from the reactions of perfluorophenyl diazomethane with activated aryl aldehydes through sulfur ylide intermediate. In contrast, under the same reaction conditions, *trans*-alkenes were obtained in excellent yield through tellurium ylide intermediates.

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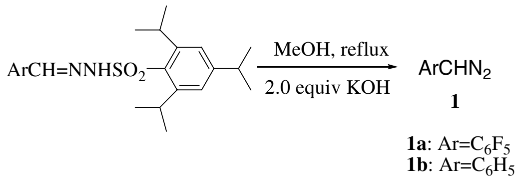
Epoxides are important synthetic intermediates that can be converted into important oxygen containing functional groups.[1] They can be synthesized from the reaction of aldehydes with unstable or semi-stable sulfur ylide intermediates, generally obtained by stepwise synthesis from the reaction of halogen alkane with Lewis base under basic conditions. However, such basic conditions and stepwise procedures often bring some inconvenience, even difficulties in the preparation of epoxides. For example, base-sensitive substrates cannot be used to synthesize the ylide intermediates under such conditions.

Transitional metals can also catalyze the formation of ylide in one-pot (one-step) reaction from the diazocompounds with Lewis base under neutral conditions. Due to the neutral conditions, it is particularly useful for unstable (or semi-stable) ylides and base-sensitive substrates. Tellurium ylide is famous for its high activity, it can react with carbonyl compounds or electron-deficient alkenes to give alkenes, epoxides, or cyclopropanes with high diastereoselectivity.[2] To our best knowledge, however, no examples for the synthesis of epoxides or alkenes from the reactions of unstable or semi-stable tellurium ylide intermediates, which were derived from telluride and diazocompounds in one-pot, have been described. To date, only three examples have been reported concerning the synthesis and isolation of stable tellurium ylides.[3]

Previously, we have reported a catalytic process for the direct coupling of aldehydes with pentafluorophenyl benzaldehyde tosylhydrazone salts to give exclusively *trans*-alkenes.[4a] However, the reaction temperature (between 35 and 45 °C) and low yields (~50%) severely restrict further application. We envisioned that the low yields may result from the low decomposition efficiency of the perfluorobenzaldehyde tosylhydrazone sodium salt. Therefore, it is necessary to find an alternative way to generate the potentially hazardous diazo compound. Reese et al. reported that 2,4,6-triisopropyl-benzenesulfonyl hydrazone was a more satisfactory intermediate than the corresponding tosyl hydrazone in the preparation of aryldiazoalkanes.[5] Thus, we firstly decided to investigate the generation of the corresponding aryldiazomethane from 2,4,6-triisopropylbenzenesulfonyl hydrazone (Scheme 1).



Scheme 1. Preparation of the pentafluorophenyl diazomethane using the Bamford–Stevens reactions.

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When arylaldehyde 2,4,6-triisopropyl-benzenesulfonyl hydrazone is refluxed with 2 M equiv of potassium hydroxide in methanol solution, it undergoes complete decomposition to give pentafluorophenyl diazomethane **1a** in greater than 95% yield and 97% purity (Table 1, entry 1). The crude products aryl diazomethane **1**, after general work-up, could be used without further purification efficiently by reducing the potential hazard and avoiding heating the tosyl salt in vacuo.

The introduction of fluorine atoms into organic molecules profoundly influences their physical and biological properties. Recently, there has been growing interest in fluorine-containing aromatic compounds owing to their unique physical properties. Herein, we report our attempts to catalytically prepare the fluorine-containing epoxides from diazo compounds.

Sulfur ylides are known for their ability to react with aldehydes, electron-poor alkenes and imines to form epoxides, cyclopropanes, and aziridines. Therefore, we wondered if the sulfur ylide generated from pentafluorophenyl diazomethane (**1a**) could react with aldehydes to give the corresponding epoxides.

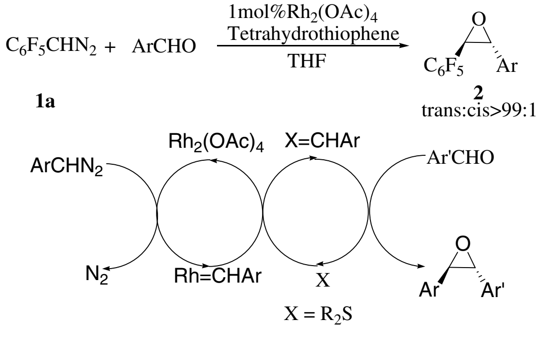
Initially, we used $Rh_2(OAc)_4$ to catalyze the decomposition of the diazocompound, and tetrahydrothiophene to trap the metal carbenenoid (Scheme 2). When 4-nitrobenzaldehyde was chosen as the substrate, it was pleasing to find that the desired epoxide **2a** was isolated in quantitative yield (Table 2, entry 1).

Table 1. Synthesis of aromatic diazomethane **1** using the Bamford–Stevens reaction

Entry	Ar	Time (min)	Yield[a] (%)	Purity[b] (%)
1	C_6F_5 (**1a**)	4	>95	>97
2	C_6H_5 (**1b**)	7	>95	>97

[a] Crude yield.

[b] Determined by ^{1}H NMR.



Scheme 2.

^{1}H NMR of epoxide **1a** showed only two signals (doublet) at δ 4.50 ppm and δ 4.00 ppm, which are attributed to the two hydrogen atoms on the epoxide ring. Their coupling constant is 1.2 Hz, which is consistent with that of *trans*-epoxide (trans: $J = 1–2$ Hz).[6] No cis-isomers were detected based on the ^{1}H NMR. This selectivity may result from the strong electron-withdrawing properties of the fluorine atoms, which can efficiently stabilize the ylide intermediates. Therefore, we hold that this reaction undergoes thermodynamic control to give the thermodynamically stable trans-isomers. Similar reaction results were also found in our early report.[4b]

Similarly, 2-nitrobenzaldehyde can also react with perfluorophenyl diazomethane **1a** to give epoxide **2b** in 89% yield. The trans-structure of the epoxide was also proven by the X-ray diffraction analysis of epoxide **2b** (Fig. 1).

It is clear from the crystal structure that the perfluorophenyl and 2-nitrophenyl are in trans positions.

This reaction is very sensitive to the properties of the aldehydes. When 4-bromobenzaldehyde was used as the reactant, only trace amount of the desired product epoxide **2c** was detected after 24 h at room temperature. Enhancing the reaction temperature to 66 °C (refluxing in THF), epoxide **2c** was isolated in 64% yield. But when benzaldehyde was used as the reactant, only trace product was detected by ^{1}H NMR in the refluxing THF. Further enhancing the reaction temperature to 80 °C (refluxing in benzene) and 110 °C (refluxing in toluene) did not improve the yield of product **2d** (Table 2, entry 4). We think that the sulfur ylide, generated in situ from diazocompound **1a** and sulfide, was not reactive enough to attack the benzaldehyde due to the strong electron-withdrawing properties of the fluorine atoms.

As mentioned above, tellurium ylide is famous for its high reactivity. It is more reactive than the corresponding sulfur ylide.[1f] Therefore, we envisioned that the tellurium ylide could react with benzaldehyde or the electron-donating group substituted aryl aldehydes to give the corresponding epoxide products. Under the similar reaction conditions, benzaldehyde was consumed in two hours at room temperature. However, the ^{1}H NMR showed that the isolated product was alkene **3a**, not the desired epoxide. Alkene **3a** was obtained in quantitative yield and with complete trans-selectivity (Scheme 3, Table 3, entry 1).

Table 2. Synthesis of epoxides **2** through sulfur ylide intermediates

Entry	ArCHO (Ar =)	Temperature	Product	Yield[a] (%)	Trans:cis[b]
1	p-$NO_2C_6H_4$–	rt	**2a**	100	>99:1
2	o-$NO_2C_6H_4$–	rt	**2b**	89	>99:1
3	p-BrC_6H_4–	Reflux	**2c**	64	>99:1
4	C_6H_5–	Reflux	**2d**	Trace	—

[a] Isolated yield.

[b] Determined by ^{1}H NMR.

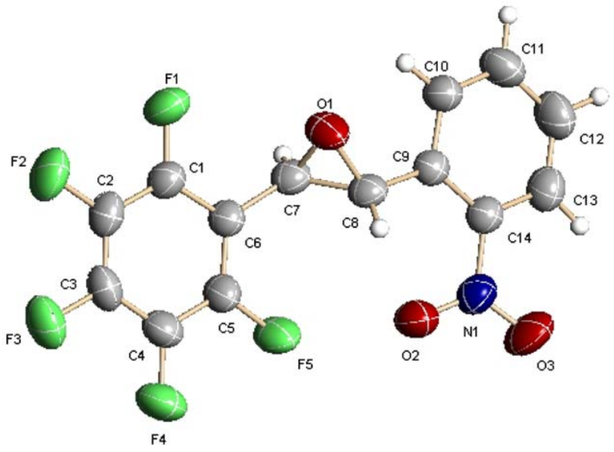
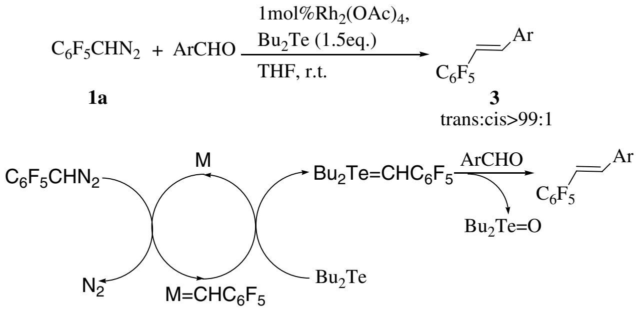


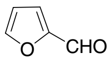
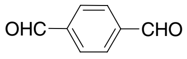
Figure 1. Structure of epoxide **2b**.



Scheme 3.

Under the same reaction conditions, a series of aldehydes were used to prepare pentafluorophenyl-containing alkenes. The results are summarized in Table 3. All aryl aldehydes except *trans*-cinnamaldehyde gave the alkenes in excellent yields and with complete trans-selectivity. Even the *trans*-cinnamaldehyde resulted in the *trans*-alkene in good yield. And heteroaromatic aldehyde (furfural) also gave the corresponding alkene in 85% yield (Table 3, entry 9). It is worthy to mention that the *trans*,*trans*-alkene can be isolated in up to 91% yield when terephthalic aldehyde was used as the reactant. The yield was only 35% in our formerly reported catalytic process for the direct coupling of aldehydes with pentafluorophenyl benzaldehyde tosylhydrazone salts to give exclusively *trans*-alkenes through the arsonium ylide intermediate.[4a] This method was not sensitive to the electronic properties of the aldehydes. Both the electron withdrawing and donating substituted aldehydes can give the corresponding alkenes in excellent yields (Table 3, entries 1–7).

Table 3. Reaction results of **1a** with aryl aldehyde through tellurium ylide

Entry	ArCHO	Product	Yield[b] (%)	Trans:cis
1	PhCHO	**3a**	99	>99:1
2	*p*-BrPhCHO	**3b**	96	>99:1
3	*o*-ClPhCHO	**3c**	94	>99:1
4	*o*-NO_2PhCHO	**3d**	92	>99:1
5	*p*-NO_2PhCHO	**3e**	90	>99:1
6	*p*-CH_3PhCHO	**3f**	95	>99:1
7	*p*-CH_3OPhCHO	**3g**	100	>99:1
8	*trans*-PhCH=CHCHO	**3h**	68	>99:1
9		**3i**	85	>99:1
10		**3j**	91	[a]

[a] Trans,trans products are obtained.

[b] Isolated yields based on aldehyde.

This reaction holds several advantages over the method we have developed to synthesize alkenes through the arsonium ylide intermediate.[4a] Although both methodologies gave exclusively *trans*-alkenes, the method described here has much higher isolated yields. Furthermore, the present reaction conditions are milder and not sensitive to the electronic properties of the aldehydes.

In summary, we described a novel and straightforward method for the synthesis of pure *trans*-pentafluorophenyl-containing alkenes from aldehydes and perfluorophenyl diazomethane in excellent yields in a one-pot reaction. The present strategy capitalizes on the reaction of aldehydes with tellurium ylides. Owing to the salt-free ylide and mild reaction conditions, this reaction is an excellent choice for the synthesis of trans aromatic alkenes, especially pentafluorophenyl-containing alkenes.

Crystal data. Compound **2b**: CCDC No.: 281928, $C_{14}H_6F_5NO_3$, $M = 331.20$; monoclinic, spacegroup $P2(1)/n$, $a = 7.2975(12)$, $b = 12.616(2)$, $c = 13.957(2)$ Å, $\alpha = 90.00$, $\beta = 95.331(3)$, $\gamma = 90.00°$, $V = 1279.4(4)$ Å^3, $Z = 4$, $D_c = 1.719$ Mg/m^3, $\mu = 0.169$ mm^{-1}, 2938 [$R_{(\text{int})} = 0.0926$] unique reflections, $F(000) = 664$, final $R_1 = 0.0446$, $wR_2 = 0.0945$, [$I > 2\delta(I)$]. Intensity data were collected at 293(2) K with a Bruker P4 four-circle diffractometer with graphite monochromator and Mo-Kα radiation [λ(Mo-Kα) = 0.71073 Å]. A total of 7535 reflections were measured in the range $5.746 < \theta < 47.612°$. The structure was solved by direct methods and expanded using Fourier techniques. The nonhydrogen atoms were refined anisotropically, hydrogen atoms were included but not refined. The final cycle of fullmatrix least-square refinement was based on F^2. All calculations were performed using the program SHELX-97.

Acknowledgements

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Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.tetlet.2006.06.065.

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