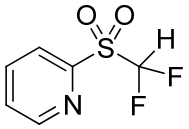
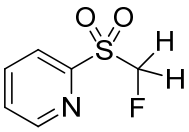
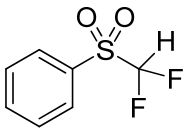
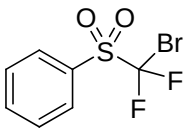
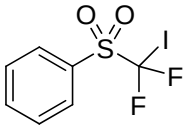
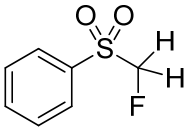
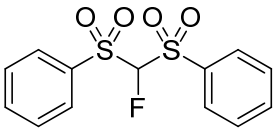
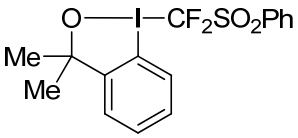
Fluoroalkylation Reagents and Applications：

A Review of Hu's Reagents

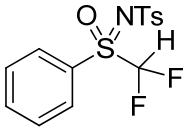
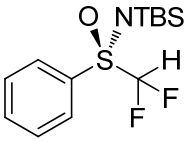
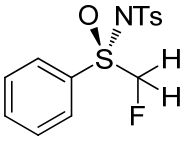
(Jul. 2014)

1. Fluorinated sulfones

Product No. *CAS Reg. No.*	Chemical Name *Acronym* MF, MW	Structure Formula	M.P. °C Purity *(^{1}H NMR)*
HU-F001 *1219454-89-3*	Difluoromethyl 2-pyridyl sulfone *(2-Py)SO_2CF_2H* $C_6H_5F_2NO_2S$ 193.17		45 – 47 ⩾ 98%
HU-F001 1365765-53-2	Fluoromethyl 2-pyridyl sulfone *(2-Py)SO_2CH_2F* $C_6H_6FNO_2S$ 175.18		83 – 85 ⩾ 98%
HU-F001 1535-65-5	Difluoromethyl phenyl sulfone *$PhSO_2CF_2H$* $C_7H_6F_2O_2S$ 192.18		*B.P.* 118 – 121 (7 Torr) ⩾ 98%
HU-F001 80351-58-2	Bromodifluoromethyl phenyl sulfone *$PhSO_2CF_2Br$* $C_7H_5BrF_2O_2S$ 271.08		33 – 34 ⩾ 98%
HU-F001 802919-90-0	Difluoroiodomethyl phenyl sulfone *$PhSO_2CF_2I$* $C_7H_5F_2IO_2S$ 318.08		66 – 68 ⩾ 98%
HU-F001 20808-12-2	Fluoromethyl phenyl sulfone *$PhSO_2CH_2F$* $C_7H_7FO_2S$ 174.1927		50 – 51 ⩾ 98%

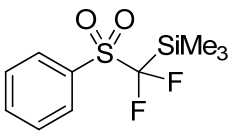
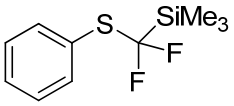
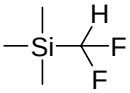
HU-F001 910650-82-7	Fluorobis(phenylsulfonyl)methane *$(PhSO_2)_2CHF$ or FBSM* $C_{13}H_{11}FO_4S_2$ 314.35		105 – 106 ⩾ 98%
HU-F001 1052174-67-0	3,3-Dimethyl-1-[difluoro(phenylsulfonyl)methyl]-1,2-benziodoxole $C_{16}H_{15}F_2IO_3S$ 452.25		89 – 90 ⩾ 98%

2. Fluorinated Sulfoximines

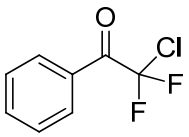
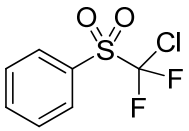
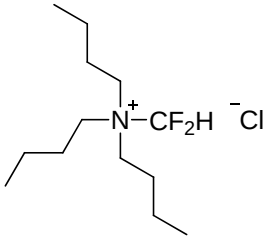
Product No *CAS Reg. No*	*Chemical Name* *Acronym* *MF, MW*	*Structure Formula*	$[\alpha]_D^{20}$ *M.P.* ^oC *Purity* *(^1H NMR)*
HU-F001 1097192-99-8	*N*-Tosyl-*S*-difluoromethyl-*S*-phenyl sulfoximine $C_{14}H_{13}F_2NO_3S_2$ 345.38		96 – 98 ⩾ 98%
HU-F001 1402352-49-1	(*R*)-*N*-(*tert*-Butyl)dimethylsilyl-*S*-difluoromethyl-*S*-phenylsulfoximine $C_{13}H_{21}F_2NOSSi$ 305.46		$[\alpha]_D^{28}$: +54.9 (*c* = 0.97, $CHCl_3$) ⩾ 98% > 99% ee
HU-F001 *Unknown*	(*R*)-*N*-Tosyl-*S*-fluoromethyl-*S*-phenylsulfoximine $C_{14}H_{14}FNO_3S_2$ 327.39		$[\alpha]_D^{24}$: +49.8 (*c* = 1.00, $CHCl_3$) 89 – 91 ⩾ 98% > 99.5% ee

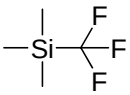
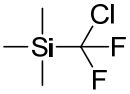
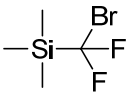
3. Fluoroalkyl silanes

Product No *CAS Reg. No*	Chemical Name *Acronym* MF, MW	Structure Formula	*B.P.* ^oC *Purity* *(^1H NMR)*

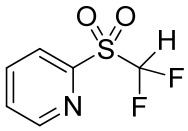
HU-F001 536975-50-5	[Difluoro(phenylsulfonyl)methyl]trimethylsilane *TMSCF$_2$SO$_2$Ph* $C_{10}H_{14}F_2O_2SSi$ 264.36		112 – 114 (1 Torr) ⩾ 98%
HU-F001 536975-49-2	[Difluoro(phenylthio)methyl]trimethylsilane *TMSCF$_2$SPh* $C_{10}H_{14}F_2SSi$ 232.37		86 – 87 (4 Torr) ⩾ 98%
HU-F001 65864-64-4	(Difluoromethyl)trimethylsilane *TMSCF$_2$H* $C_4H_{10}F_2Si$ 124.20		86 – 87 ⩾ 98%

4. Difluorocarbene reagents

Product No *CAS Reg. No*	Chemical Name *Acronym* MF, MW	Structure Formula	*B.P.* ^oC *Purity* *(^{1}H NMR)*
HU-F001-1 384-67-8	2-Chloro-2,2-difluoro-1-phenylethanone *PhCOCF$_2$Cl* $C_8H_5ClF_2O$ 190.57		94 – 96 (35 Torr) ⩾ 97%
HU-F001-2 930836-30-9	Chlorodifluoromethyl phenyl sulfone *PhSO$_2$CF$_2$Cl* $C_7H_5ClF_2O_2S$ 226.63		*M.P.* 32 – 33 ⩾ 97%
HU-F001 1004517-48-9	Difluoromethyltributylammonium chloride $C_{13}H_{28}ClF_2N$ 271.82		*M.P.* 91 – 93 ⩾ 97%

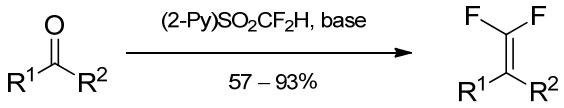
HU-F001 81290-20-2	Trimethyl(trifluoromethyl)silane *$TMSCF_3$ or Ruppert-Prakash reagent* $C_4H_9F_3Si$ 142.19		55 – 55.5 ⩾ 98%
HU-F001-1 115262-00-5	(Chlorodifluoromethyl)trimethylsilane *$TMSCF_2Cl$ or CDFS* $C_4H_9ClF_2Si$ 158.65		80 – 82 ⩾ 98%
HU-F001-2 115262-01-6	(Bromodifluoromethyl)trimethylsilane *$TMSCF_2Br$ or BDFS* $C_4H_9BrF_2Si$ 203.10		106 – 108 ⩾ 98%

Technical Notes of HU-F001



Difluoromethyl 2-pyridyl sulfone, a previously unknown compound that can be readily prepared from 2-mercaptopyridine, is a novel and efficient *gem*-difluoroolefination reagent for preparing *gem*-difluoroalkenes from both aldehydes and ketones. The fluorinated sulfinate intermediates during the *gem*-difluoroolefination is relatively stable, and can be halogenated in situ to afford bromo- and iododifluoromethyl compounds. It can also act as nucleophilic difluoro(sulfonato)methylation reagent for the synthesis of α,α-difluorosulfonates from aldehydes, and alkyl halides and triflates.

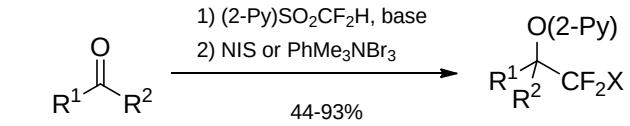
(1) *gem*-Difluoroolefination of aldehydes and ketones.



R^1, R^2 = H, alkyl, allyl, aryl

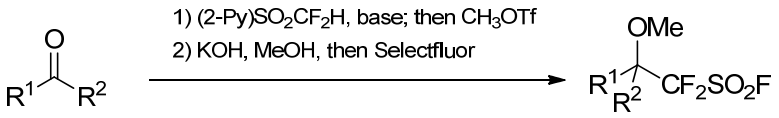
Ref. Org. Lett. 2010, 12, 1444 – 1447.

(2) Halodifluoromethylation of aldehydes and ketones.



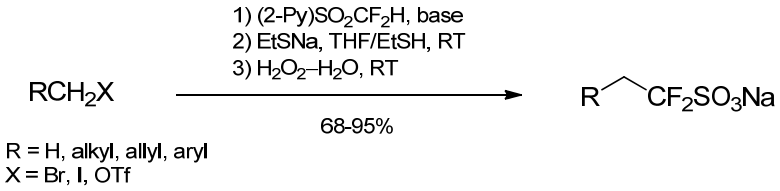
Ref. J. Am. Chem. Soc. 2012, 134, 5790 – 5793

(3) (Fluorosulfonyl)difluoromethylation of aldehydes and ketones.



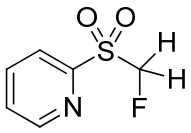
Ref. Sci. Sin. Chim. 2011, 41, 1833 – 1839

(4) Difluoro(sulfonato)methylation of alkyl halides and triflates.



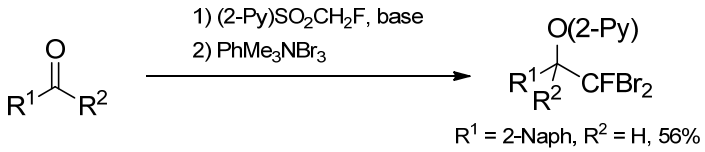
Ref. Angew. Chem. Int. Ed. 2011, 50, 2559 – 2563

Technical Notes of HU-F001



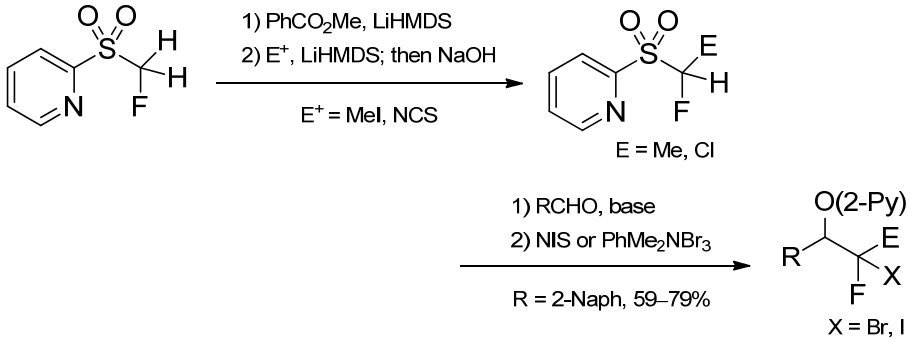
Fluoromethyl 2-pyridyl sulfone and its derivatives can be used as novel monofluoromethylation reagents. The monofluorinated sulfinate intermediates during the monofluoroolefination of aldehydes and ketones can be halogenated in situ to afford mono- and dihalofluoroalkyl compounds. The coupling reaction between iodofluoromethyl 2-pyridyl sulfone and aryl iodides mediated by copper can be used to prepare monofluoromethyl arenes and heteroarenes.

(1) Dihalofluoromethylation of aldehydes and ketones.



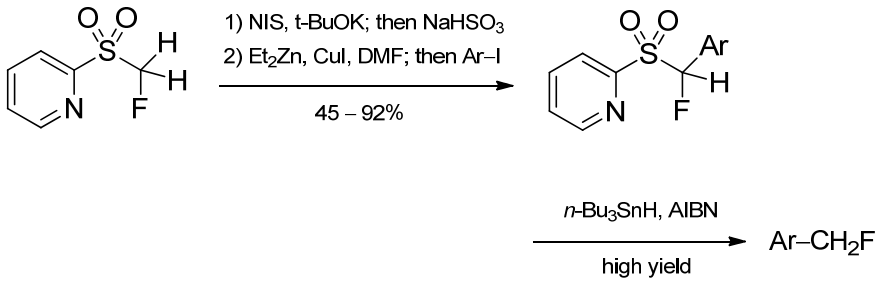
Ref. J. Am. Chem. Soc. 2012, 134, 5790 – 5793

(2) Halofluoroalkylation of aldehydes.



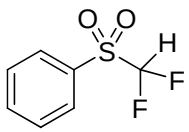
Ref. J. Am. Chem. Soc. 2012, 134, 5790 – 5793

(3) Monofluoromethylation of arenes and heteroarenes.



Ref. Org. Lett. 2012, 14, 6080 – 6083.

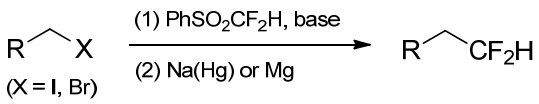
Technical Notes of HU-F001



Difluoromethyl phenyl sulfone is a powerful nucleophilic difluoromethylation reagent due to the high reactivity of the sulfonyl-stabilized difluoromethyl anion towards many electrophiles

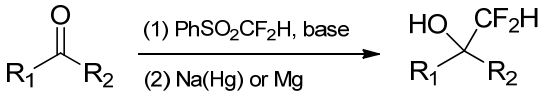
including carbonyls, imines, alkyl halides, and cyclic sulfates and sulfamidates. In the nucleophilic reaction step, depending on the substrate structure, strong bases are used to generate the nucleophilic (phenylsulfonyl)difluoromethyl anion in situ. In the desulfonylation step, sodium/mercury amalgam and magnesium are the commonly used reductive reagents. Besides, the (phenylsulfonyl)difluoromethylated compounds can undergo β-elimination to afford *gem*-difluoroalkenes.

(1) Difluoromethylation of alkyl halides.



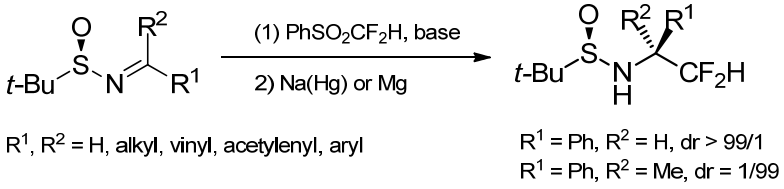
Ref. Org. Lett. 2004, 6, 4315 – 4317.

(2) Difluoromethylation of aldehydes and ketones.



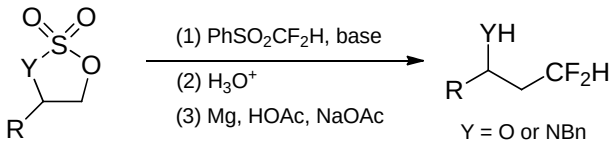
Ref. Eur. J. Org. Chem., 2005, 2218 – 2223

(3) Difluoromethylenation of aldimines and ketimines.



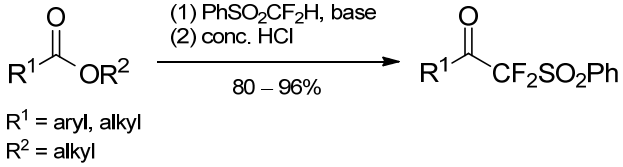
Refs. 1) Angew. Chem. Int. Ed., 2005, 44, 5882 – 5886; 2) J. Org. Chem., 2007, 72, 3119 – 3121; 3) Chem. Eur. J. 2010, 16, 11443 – 11454.

(4) Difluoromethylation of cyclic sulfates and sulfamidates.



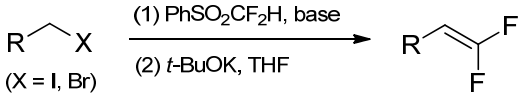
Ref. Angew. Chem. Int. Ed. 2007, 46, 786 –789.

(5) (Phenylsulfonyl)difluoromethylation of carboxylic acid esters.



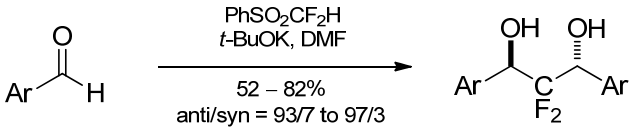
Ref. J. Org. Chem. 2009, 74, 3767–3771.

(6) Difluoromethylenation of alkyl halides.



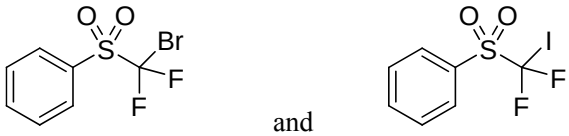
Refs. 1) Angew. Chem. Int. Ed., 2004, 43, 5203 – 5206; 2) Angew. Chem. Int. Ed. 2007, 46, 786 –789.

(7) Difluoromethylenation of aromatic aldehydes.



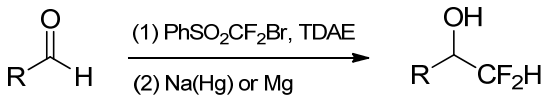
Ref. Angew. Chem. Int. Ed., 2003, 42, 5216 – 5219.

Technical Notes of HU-F001-1 and HU-F001-2



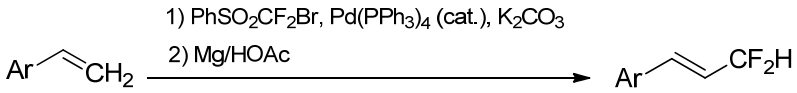
The nucleophilic reactions of bromodifluoromethyl phenyl sulfone with electrophiles such as aldehydes in the presence of TDAE affords (phenylsulfonyl)difluoromethyl-containing synthetically useful intermediates. Palladium-mediated reactions of styrene derivatives, vinyl ethers, and heteroaromatics with bromodifluoromethyl phenyl sulfone in the presence of potassium carbonate affords the (phenylsulfonyl)difluoromethylated products. Iododifluoromethyl phenyl sulfone can be used for the difluoromethylation of alkenes and alkynes initiated by triethylborane/air or arenediazonium salt/titanium chloride in moderate to good yields.

(1) Difluoromethylation of aldehydes.



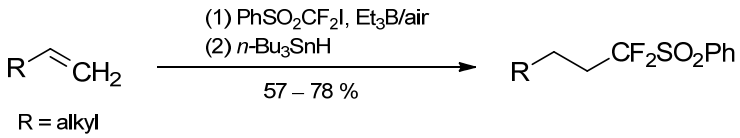
Ref. J. Fluorine Chem. 2005, 126, 1361–1367.

(2) Difluoromethylation of styrenes, vinyl ethers, and heteroaromatics.



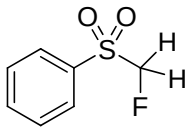
Ref. Eur. J. Org. Chem. 2012, 5943–5952.

(3) Difluoromethylation of terminal alkenes and alkynes.



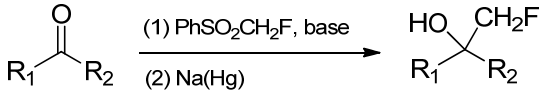
Refs. 1) J. Org. Chem., 2007, 72, 5824; 2) Tetrahedron, 2009, 65, 478.

Technical Notes of HU-F001



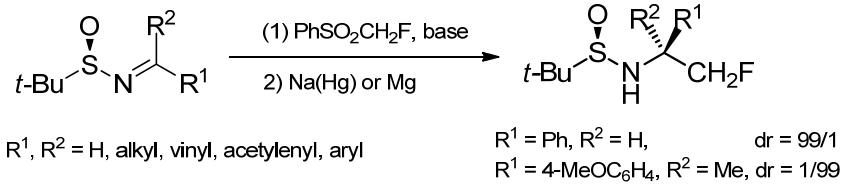
Fluoromethyl phenyl sulfone is a useful nucleophilic monofluoromethylation reagent for the synthesis of fluoromethyl alcohols and amines. In the nucleophilic reaction step, strong bases such as LiHMDS and *n*-BuLi are used to generate the nucleophilic (phenylsulfonyl)fluoromethyl anion. In the desulfonylation step, sodium/mercury amalgam and magnesium are the commonly used reductive reagents. Besides, the addition reaction between fluoromethyl phenyl sulfone and carbonyls can be used to prepare monofluoroaklenes via acylation–elimination.

(1) Monofluoromethylation of aldehydes and ketones.



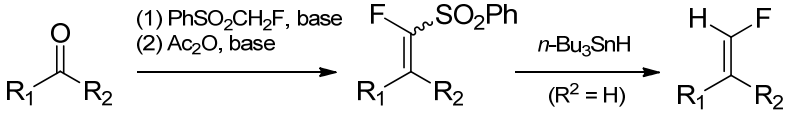
Ref. J. Org. Chem. 2008, 73, 5699.

(2) Monofluoromethylation of aldimines and ketimines.



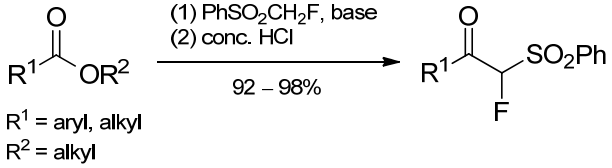
Refs. 1) Org. Lett. 2006, 8, 1693; 2) Org. Lett. 2008, 10, 5377.

(3) Monofluoromethylenation of aldehydes and ketones.



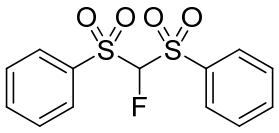
Ref. J. Chem. Soc., Chem. Commun. 1985, 678.

(4) (Phenylsulfonyl)fluoromethylation of esters.



Ref. J. Org. Chem. 2009, 74, 3767–3771.

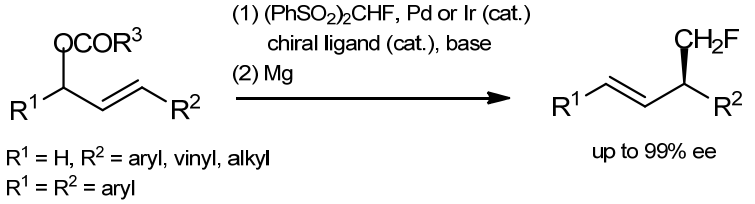
Technical Notes of HU-F001



Fluorobis(phenylsulfonyl)methane (FBSM), can be deprotonated under much milder basic conditions than those required for the deprotonation of fluoromethyl phenyl sulfone, and thus has been used as an excellent nucleophilic fluoromethylation reagent in many catalytic asymmetric reactions with allyl esters, imines, and α,β-unsaturated compounds. Stereoselctive nucleophilic substitution reaction between chiral alcohols and FBSM under Mitsunobu conditions gives the fluoromethylated products with full inversion of the configuration. Nucleophilic substitution

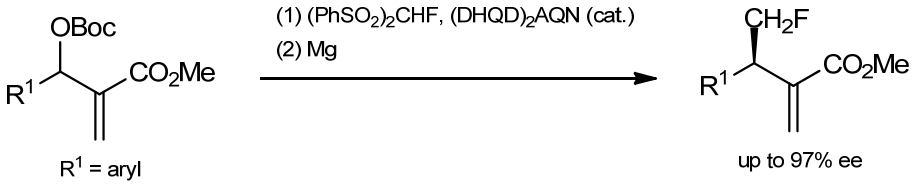
reaction of epoxides and aziridines with FBSM gives the precursors of β-fluoromethylated alcohols and amines in high yields. As a carbon acid, FBSM can also be used in cross dehydrogenative coupling reaction.

(1) Monofluoromethylation of allyl esters.



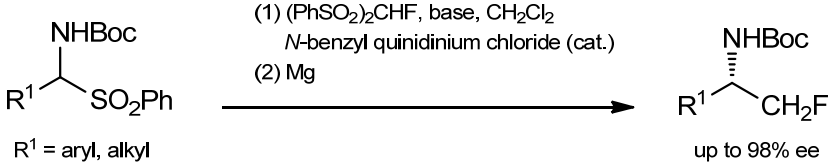
Refs. 1) Angew. Chem. Int. Ed. 2006, 45, 4973-4977; 2) Chem. Commun. 2009, 6604-6606.

(2) Monofluoromethylation of Morita–Baylis–Hillman carbonates.



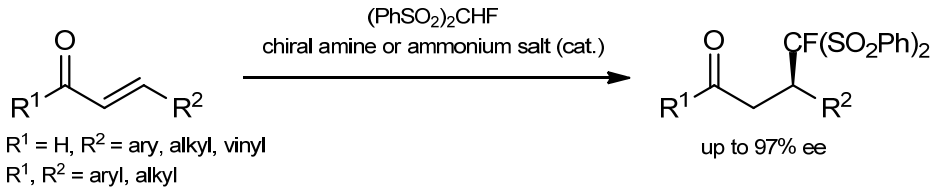
Ref. Angew. Chem. Int. Ed. 2011, 50, 9684

(3) Monofluoromethylation of imines.



Ref. J. Am. Chem. Soc. 2007, 129, 6394-6395.

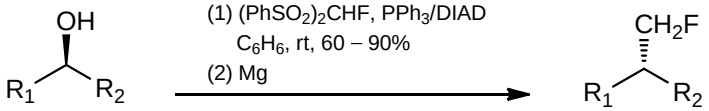
(4) Monofluoromethylation of α,β-unsaturated ketones and aldehydes.



Ref. 1) Angew. Chem. Int. Ed. 2008, 47, 8051-8054; 2) Chem. Eur. J. 2009, 15, 7035; 3)

Tetrahedron Lett. 2009, 50, 4896-4898.

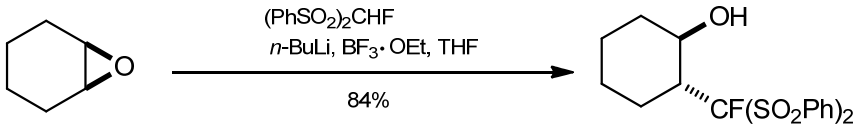
(5) Monofluoromethylation of α,β-unsaturated ketones and aldehydes.



R^1, R^2 = alkyl, vinyl, ary

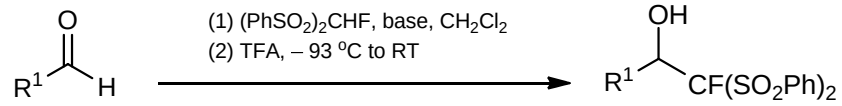
Ref. Angew. Chem. Int. Ed. 2007, 46, 4933.

(6) Monofluoromethylation of epoxides.



Ref. J. Org. Chem. 2006, 71, 6829-6833.

(7) Monofluoromethylation of aldehydes.

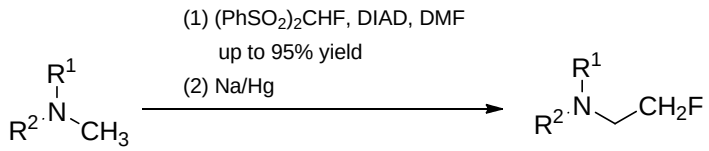


R^1 = aryl, alkyl

82 – 95%

Ref. Angew. Chem. Int. Ed. 2011, 50, 2588 –2592

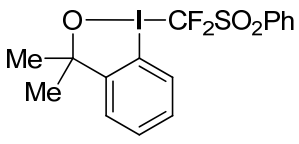
(8) Monofluoromethylation of tertiary amines.



R^1, R^2 = alkyl

Ref. New J. Chem. 2013, 42, 10.1039/C2NJ40842B.

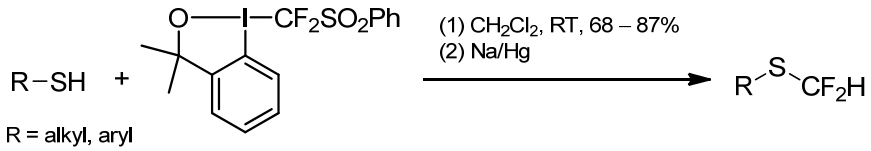
Technical Notes of HU-F001



A novel electrophilic difluoromethylation reagent prepared from $TMSCF_2SO_2Ph$, which can

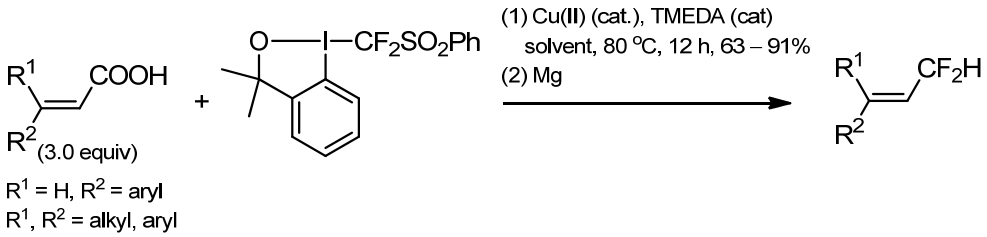
efficiently transfer the $PhSO_2CF_2$ moiety to nucleophiles such as thiols under mild reaction conditions. Copper(II)-catalyzed decarboxylative difluoro(phenylsulfonyl)methylation of α,β- or β,γ-unsaturated carboxylic acids with this reagent can afford vinylic and allylic difluoromethylation products.

(1) Difluoromethylation of thiols.



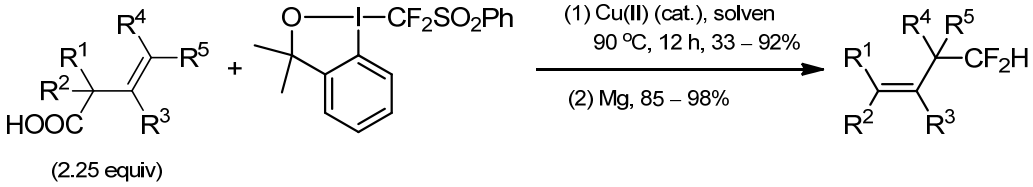
Ref. Tetrahedron Lett. 2008, 49, 5006.

(2) Difluoromethylation of β,γ-unsaturated carboxylic acids.



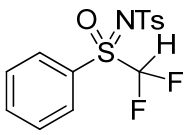
Ref. Angew. Chem. Int. Ed. 2012, 51, 3944 –3947.

(3) Difluoromethylation of α,β-unsaturated carboxylic acids.



Ref. Angew. Chem. Int. Ed. 2012, 51, 11545–11547.

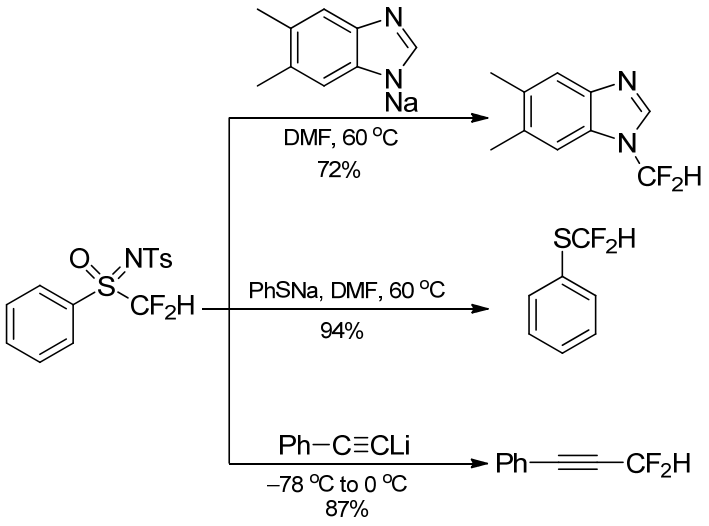
Technical Notes of HU-F001



A novel and efficient difluoromethylation reagent for transferring the CF_2H group to *S*-, *N*-, and

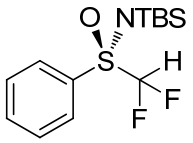
C-nucleophiles under water-free conditions.

(1) Difluromethylation of *S*-, *N*-, and *C*-nucleophiles.



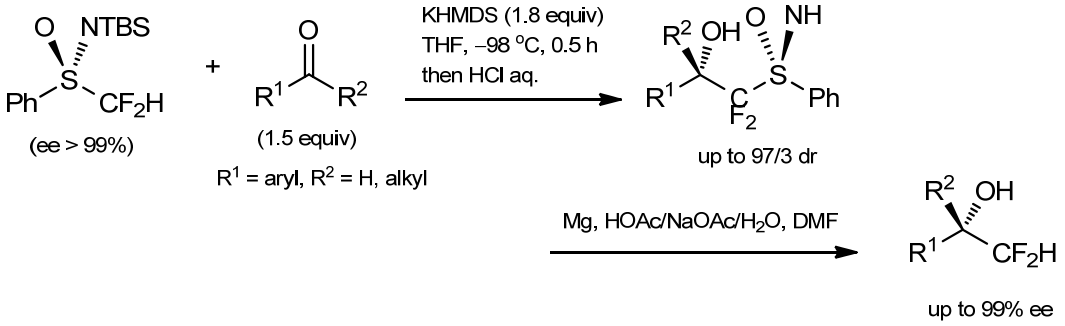
Ref. Org. Lett., 2009, 11, 2109-2112.

Technical Notes of HU-F001



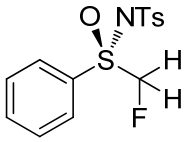
A novel chiral difluoromethylation reagent towards electrophiles such as aldehydes and ketones. Reductive desulfonimidoylation of the addition products with magnesium can afford difluoromethyl alcohols with high enantiopurity. This reagent is useful for the synthesis of enantioenriched difluoromethyl alcohols, especially the tertiary alcohols.

(1) Difluoromethylation of aldehydes and ketones.



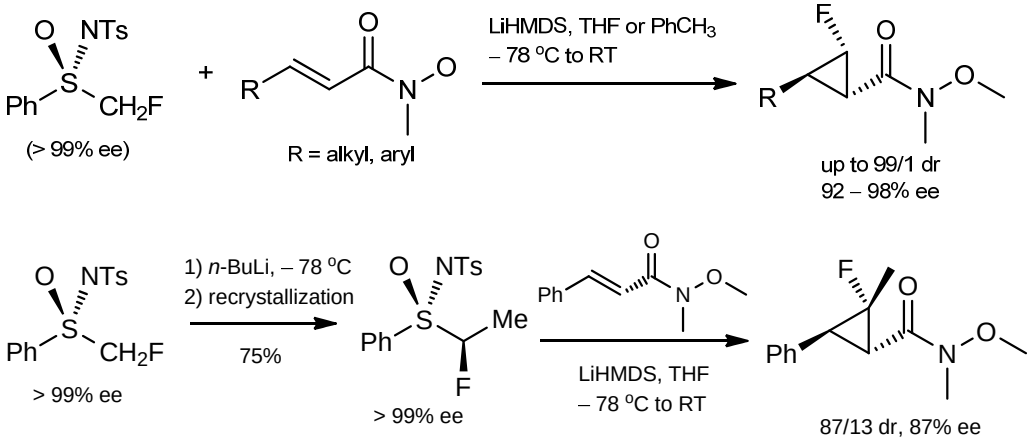
Ref. J. Am. Chem. Soc. 2012, 134, 16999−17002.

Technical Notes of HU-F001



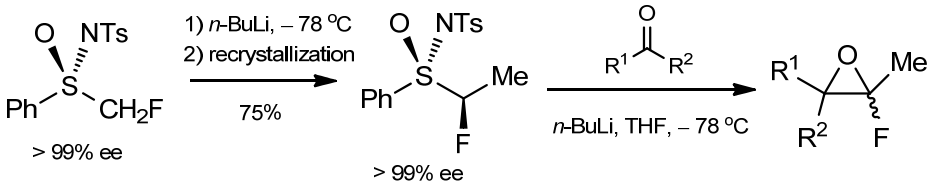
A novel chiral monofluoromethylenation reagent towards electrophiles such as α,β-unsaturated Weinreb amides. The reaction is general and a variety of structurally diverse α,β-unsaturated Weinreb amides can be monofluoromethylenated to give the corresponding monofluorinated cyclopropanes in good yield, with good diastereoselectivity, and with excellent enantioselectivity.

(1) Monofluoromethylenation of α,β-unsaturated Weinreb amides.



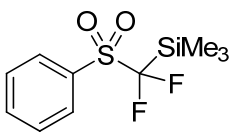
Ref. Angew. Chem. Int. Ed. 2012, 51, 6966 – 6970.

(2) Monofluoromethylenation of ketones.



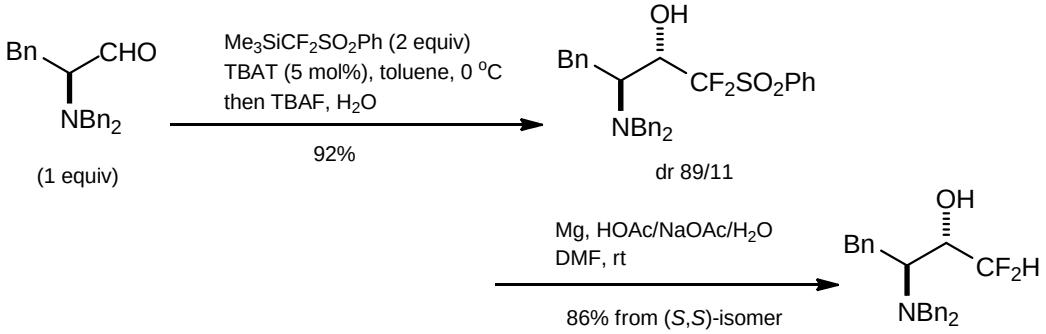
Ref. Adv. Synth. Catal. 2010, 352, 2799 – 2804.

Technical Notes of HU-F001



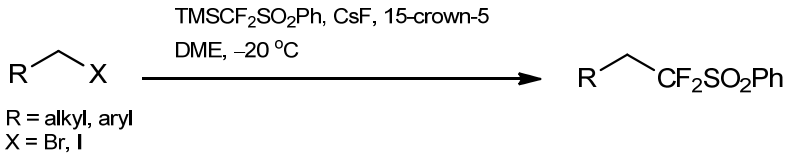
A much milder difluoro(phenylsulfonyl)methylation reagent than difluoromethyl phenyl sulfone. Under the action of Lewis bases such as such as tetrabutylammonium triphenyldifluorosilicate (TBAT), potassium fluoride, potassium hydrodifluoride, and potassium carbonate, difluoro(phenylsulfonyl)methyl can be transferred to aldehydes, ketones, alkyl halides, and non-activated imines.

(1) Difluoromethylation of aldehydes and ketones.



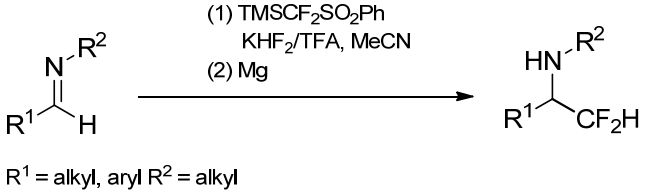
Ref. Tetrahedron Lett. 2008, 49, 1605 – 1608.

(2) Difluoromethylation of alkyl halides.



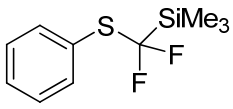
Ref. Tetrahedron Lett. 2010, 51, 6150 – 6152.

(3) Difluoromethylation of imines and enamines.



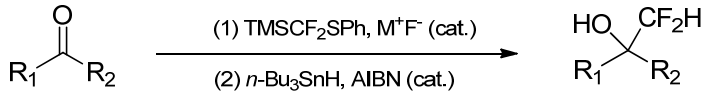
Ref. J. Org. Chem. 2012, 77, 2080−2086.

Technical Notes of HU-F001



An effective reagent to introduce difluoromethyl groups into carbonyls, imines, enamines, and alkyl halides. Not only various simple aldehydes and ketones, but also functionalized carbonyls such as α- and γ-ketoesters and cyclic imides can be difluoro(phenylthio)methylated in high yields under the activation of a catalytic amount of Lewis bases. The substitution reaction proceeds well with primary alkyl bromides and iodides as the limiting reactant when cesium fluorode/15-crown-5 is used as the fluoride source/additive. Under radical conditions, the difluoro(phenylthio)methyl compounds containing vinyl functional groups can form 5- or 6-membered rings via intramolecular cyclization.

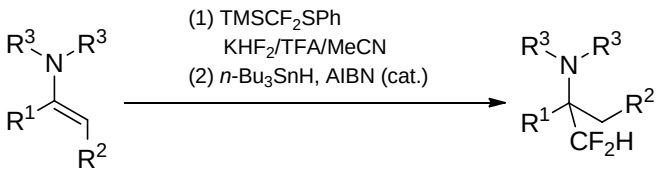
(1) Difluoromethylation of aldehydes and ketones.



R^1, R^2 = H, alkyl, vinyl, aryl

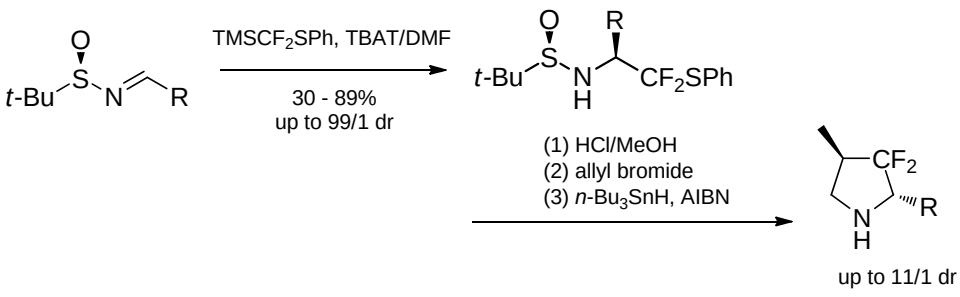
Ref. J. Org. Chem. 2009, 74, 3798–3805

(2) Difluoromethylation of imines and enamines.



Ref. J. Org. Chem. 2012, 77, 2080−2086.

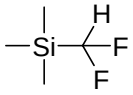
(3) (Phenylthio)difluoromethylation of imines for further cyclizations.



Ref. Angew. Chem., Int. Ed. 2007, 46, 2489–2492.

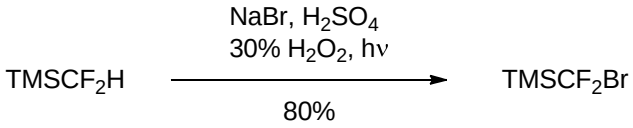
(4) Difluoromethylation of alkyl halides.

Technical Notes of HU-F001



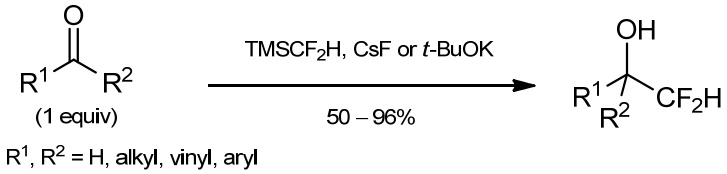
A direct nucleophilic difluoromethylation reagent. The nucleophilic activation of the silicon center with Lewis base initiators allows transfer of the difluoromethyl moiety to electrophiles such as aldehydes, ketones, and aldimines. The copper-mediated difluoromethylation of halides using $TMSCF_2H$ tolerates amine, ether, amide, ester, aromatic bromide, and protected alcohol functionalities in aryl iodides and occurs in high yield and stereoselectivity with vinyl iodides.

(1) Direct bromination to prepare $TMSCF_2Br$



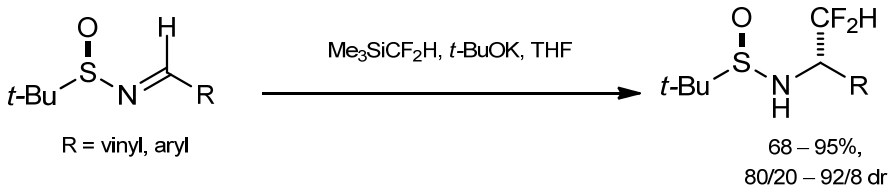
Ref. J. Org. Chem. 2012, 77, 5850 − 5855.

(2) Difluoromethylation of aldehydes and ketones.



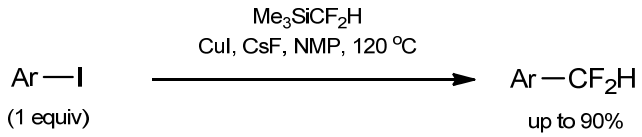
Ref. Org. Lett., 2011, 13, 5342 – 5345.

(3) Difluoromethylation of aldimines.



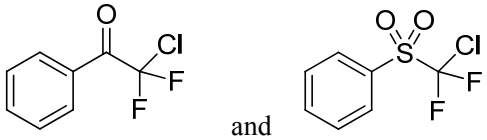
Ref. Org. Lett., 2011, 13, 5342 – 5345.

(4) Difluoromethylation of aryl and vinyl iodides.



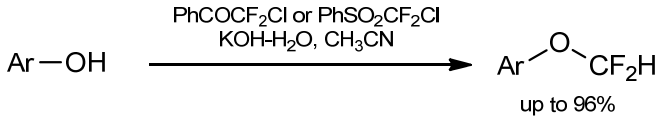
Ref. J. Am. Chem. Soc. 2012, 134, 5524−5527.

Technical Notes of HU-F001 and HU-F001



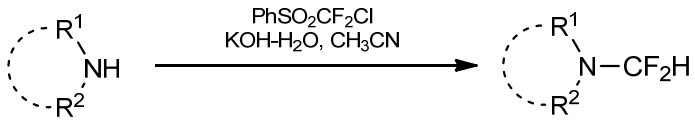
Novel and non-ODS-based (ODS = ozone-depleting substance) difluorocarbene reagents for *O*- and *N*-difluoromethylation. $PhCOCF_2Cl$ reacts with a variety of structurally diverse phenol derivatives to produce aryl difluoromethyl ethers in good yields. $PhSO_2CF_2Cl$ can react with a variety of structurally diverse phenol derivatives and *N*-heterocyclic compounds.

(1) *O*-difluoromethylation.



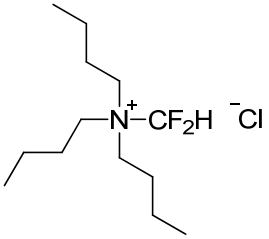
Refs. 1) Chem. Commun., 2007, 5149–5151; 2) J. Org. Chem. 2006, 71, 9845–9848.

(2) *N*-difluoromethylation.



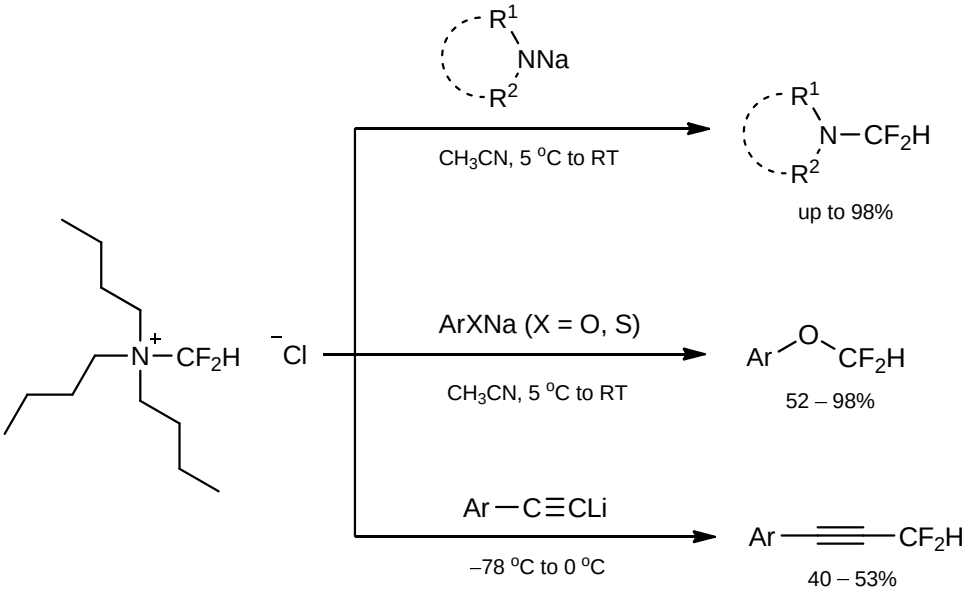
Ref. 1) Chem. Commun., 2007, 5149–5151.

Technical Notes of HU-F001



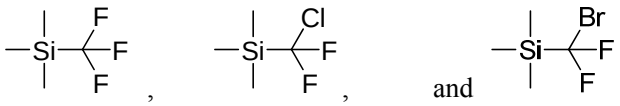
A novel and effective difluorocarbene reagent for *O*-, *S*-, *N*-, *C*-difluoromethylation under mild conditions. When only 1.2 equivalent of the reagent is used, the difluoromethylated products can be obtained in moderate to excellent yields at low temperatures.

(1) *O*-, *S*-, *N*-, *C*-difluoromethylation



Ref. Chin. J. Chem. 2011, 29, 2717–2721.

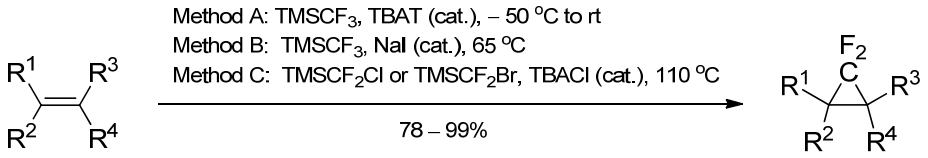
Technical Notes of HU-F001, HU-F001, and HU-F001.



Novel difluorocarbene reagents for the synthesis of gem-difluorinated cyclopropanes and cyclopropenes from alkenes and alkynes. $TMSCF_3$ can be used to generate difluorocarbene at low temperatures using TBAT as the initiator or at higher temperatures using NaI as the as the initiator. $TMSCF_2Cl$ and $TMSCF_2Br$ can be used to generate difluorocarbene at higher temperatures catalyzed by chloride ion. Reactions of difluorocarbene generated from $TMSCF_2Br$ with TMSCN,

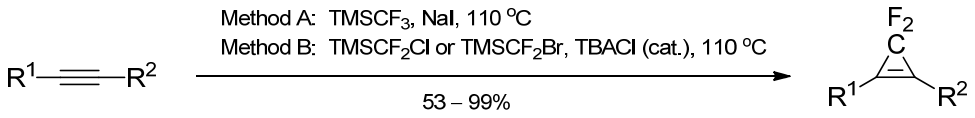
and benzyl and alkylzinc halides leading to new difluorinated organometallic reagents.

(1) Difluoromethylenation of alkenes.



Refs. 1) Angew. Chem. Int. Ed. 2011, 50, 7153 –7157; 2) Chem. Commun. 2011, 47, 2411–2413.

(2) Difluoromethylenation of alkynes.

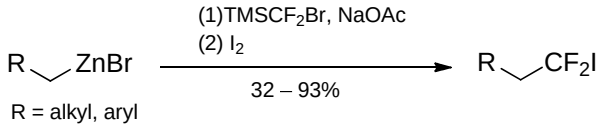


Refs. 1) Angew. Chem. Int. Ed. 2011, 50, 7153 –7157; 2) Chem. Commun. 2011, 47, 2411–2413.

(3) Difluoromethylenation of TMSCN.

Ref. J. Org. Chem. 2012, 77, 5850−5855.

(4) Difluoromethylenation of benzyl and alkylzinc halides.



Ref. Org. Lett. 2013, 15, 917 – 919.