Seminar

The Reactivity of Vinyl Cations in TM-Free Condition

Reporter: Shi Yixiang (石逸翔)
Supervisor: Prof. Zhang Junliang
Dr. Yang Junfeng

2023-03-31

Contents

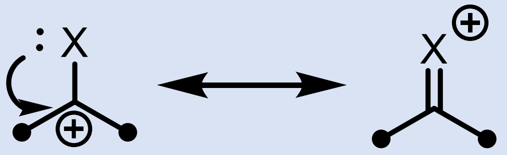
Contents

1. Introduction

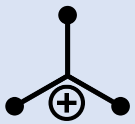
Tricoordinated carbocation & dicoordinated carbocation

tricoordinated carbocation

stablized



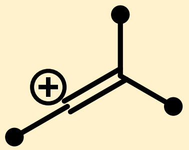
carbenium



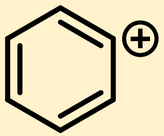
sp^2-hybridized
resonance & hyperconjugation
many methods for generation
known in asymmetric catalysis

dicoordinated carbocation

vinyl cation



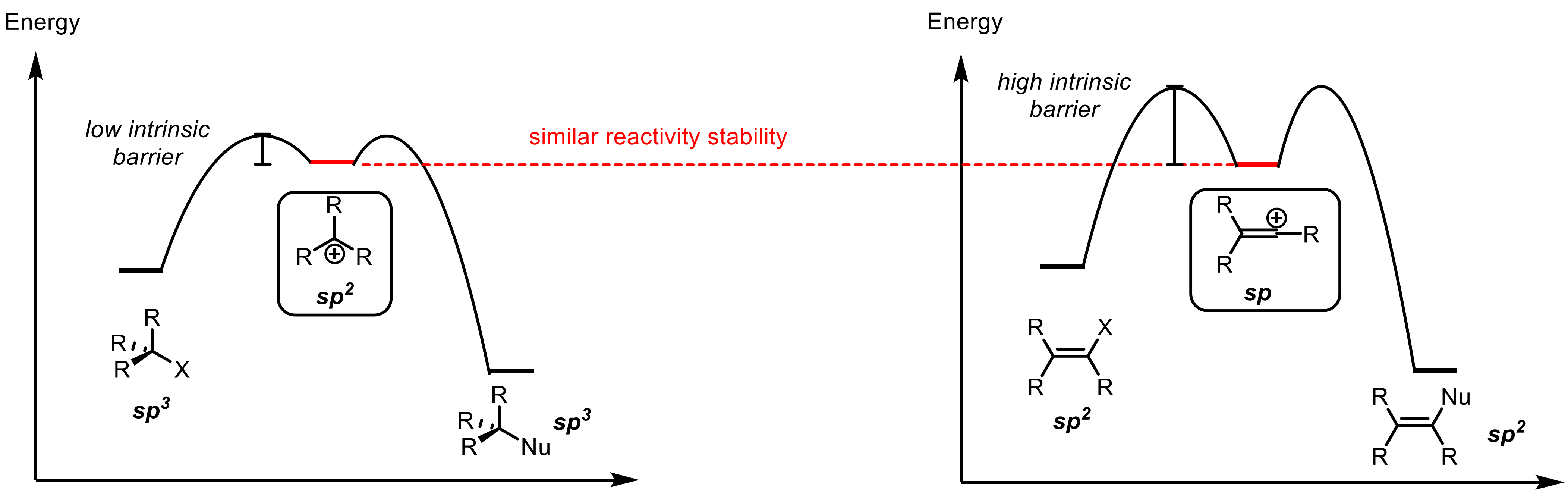
aryl cation



high s orbital character
minimized resonance & hyperconjugation
chanllenging formation
unknown in asymmetric catalysis

D. A. Klumpp, et. al. *Chem. Rev.* **2013**, *113*, 6905−6948.
S. Gao, et. al. *Angew. Chem. Int. Ed.* **2018**, *57*, 16942–16944.

1. Introduction



classical S_N1 reaction

vinyl cation driven S_N1-type reaction

Carbocation:

- Low intrinsic barrier
- Stable intermediate
- Multiple reactions

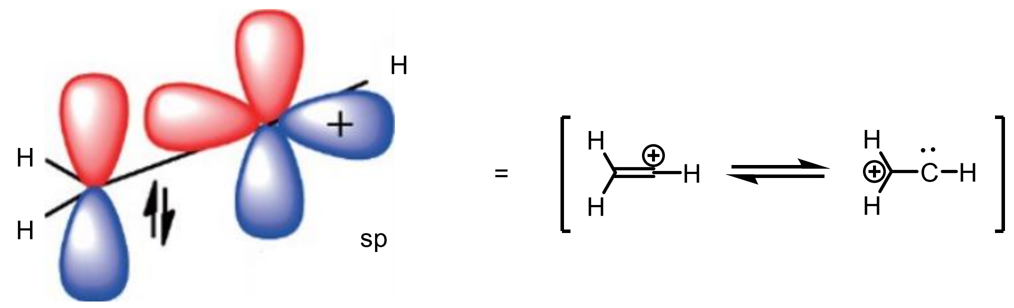
Vinyl cation:

- High intrinsic barrier
- Unstable intermediate
- Possibility of C-H insertion

H. O. Smith, et. al. *Angew. Chem. Int. Ed.* **1972**, *11*, 635–636.

1. Introduction

Vinyl cation (Resemble with methylene bearing a CH_2^+ substituent)

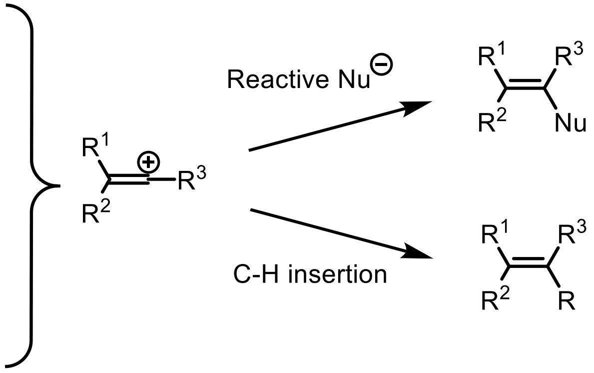


Ionization of vinly triflates

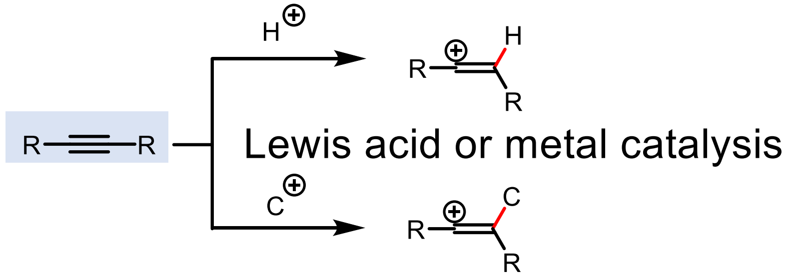
Additon of electrophiles to alkynes

Tandem cyclization of enynes or diynes

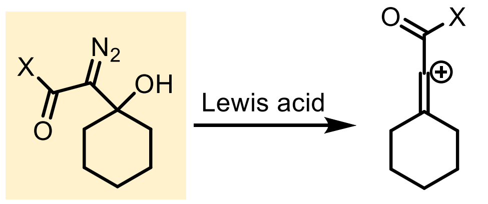
Decomposition of α-diazo ketones



Vinyl Cations Produced by Alkynyl Group

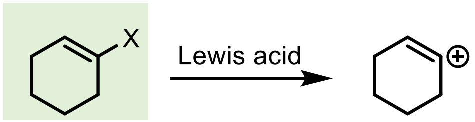


Vinyl Cations Produced by α-diazo Compounds



X = OMe, NMe_2, ^{t}Bu

Vinyl Cations Produced in Situ by Vinyl Compounds

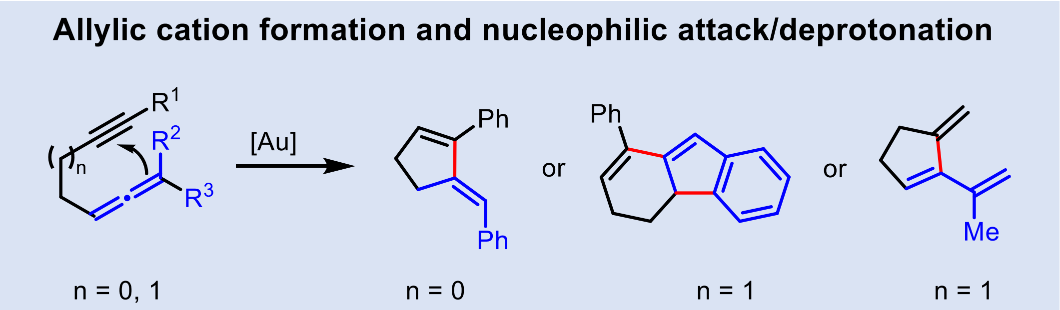


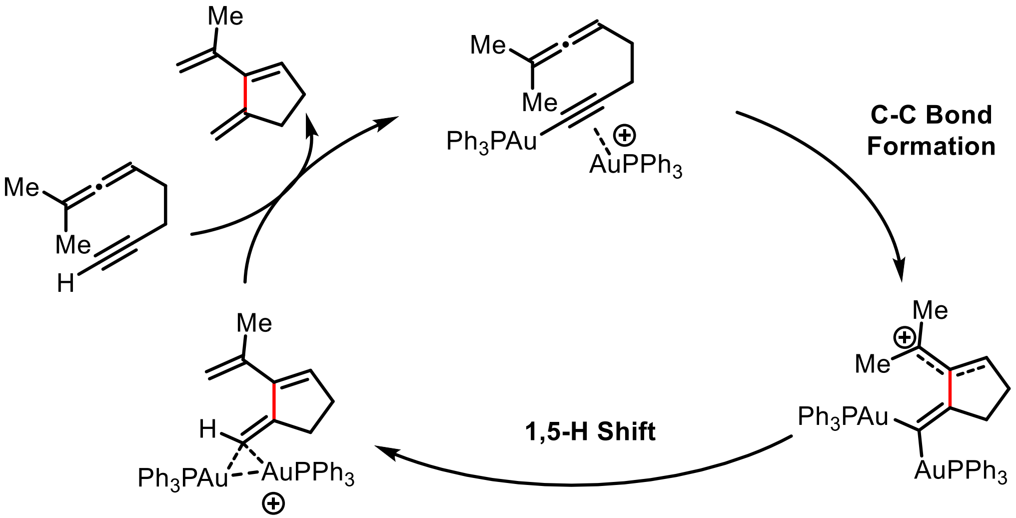
X = OTf, OTs, BPin

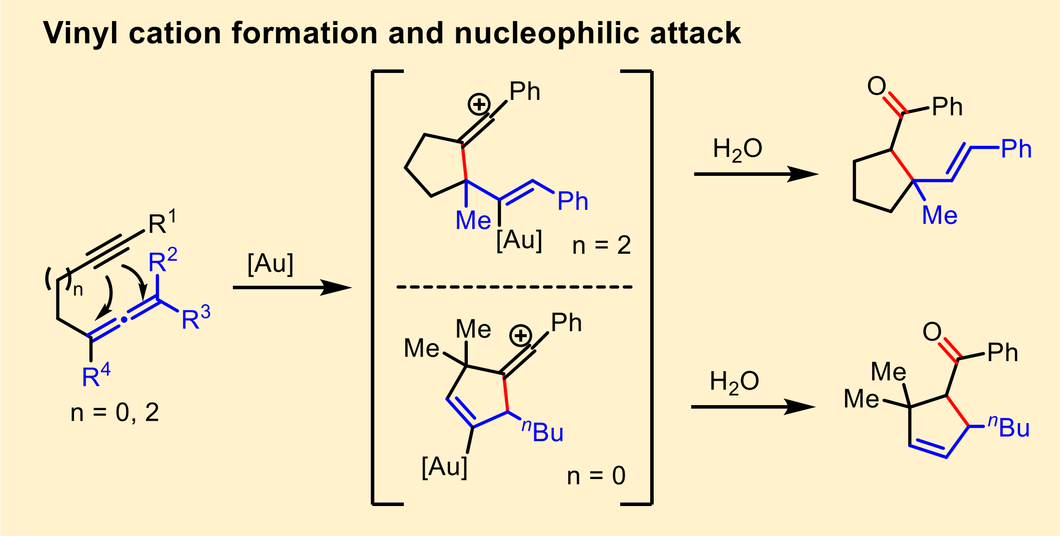
S. Searles, et. al. *J. Am. Chem. Soc.* **1944**, *66*, 686–689.
G. Cseh, et. al. *Helv. Chim. Acta.* **1964**, *47*, 1590–1602.

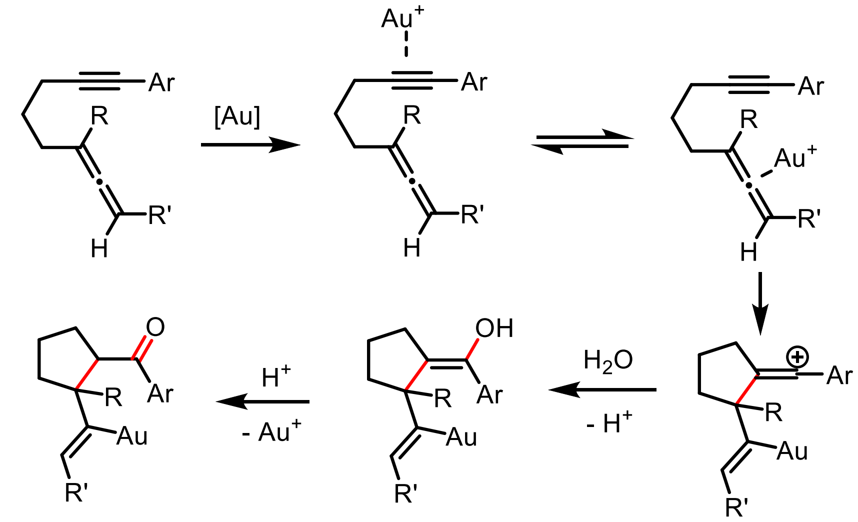
1. Introduction

Vinyl cation by alkyne and allene with gold catalysis





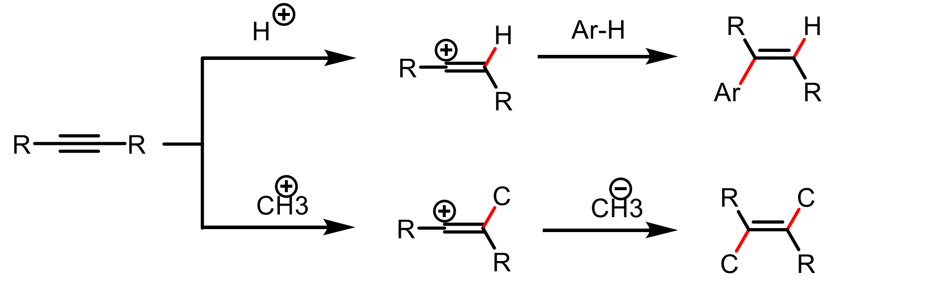


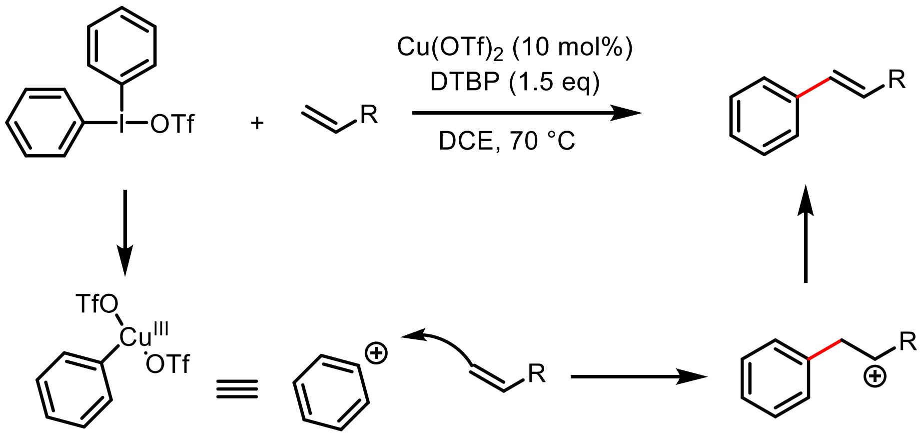


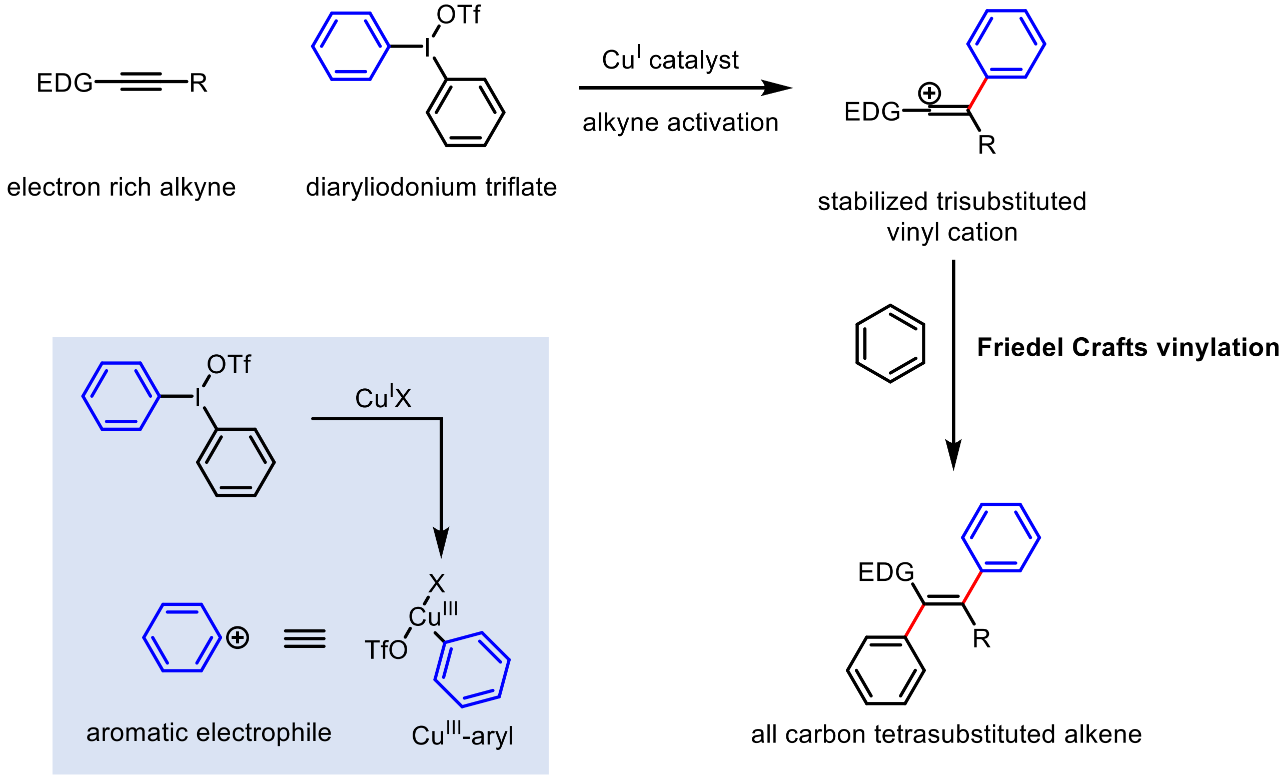
K. N. Houk, F. D. Toste, et. al. *J. Am. Chem. Soc.* **2008**, *130*, 4517–4526.
R. S. Liu, et. al. *J. Org. Chem.* **2008**, *73*, 4907–4914.

1. Introduction

Vinyl cation by alkyne with copper catalysis





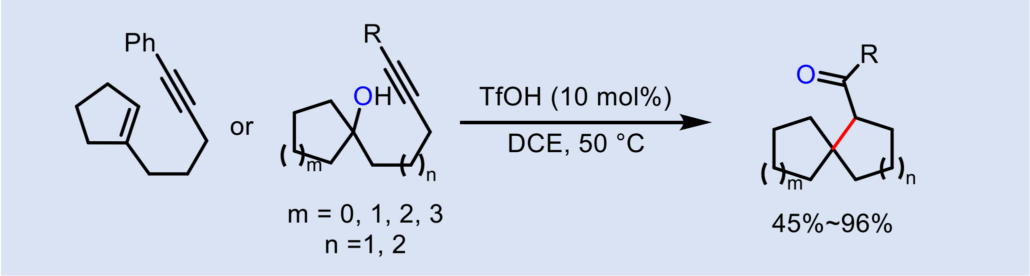


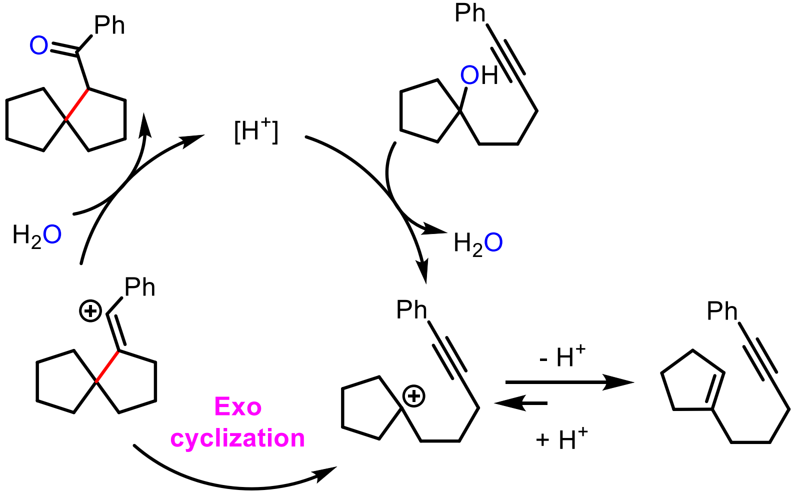
M. J. Gaunt, et. al. *J. Am. Chem. Soc.* **2012**, *134*, 10773−10776.
M. J. Gaunt, et. al. *J. Am. Chem. Soc.* **2013**, *135*, 12532−12535.

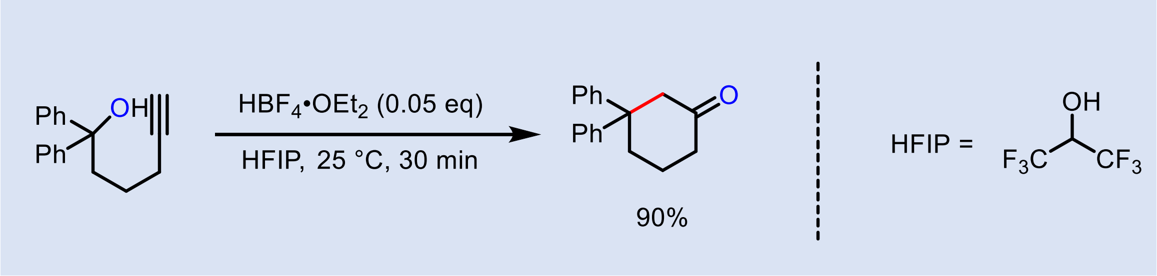
Contents

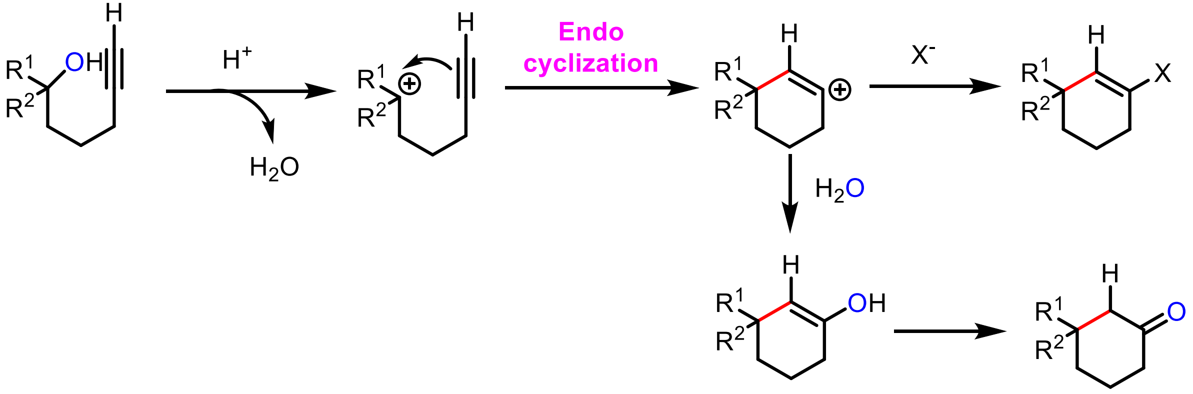
2.1 Vinyl Cations Produced by Alkynyl Group

Ring closing reaction of alkyne with carbocation





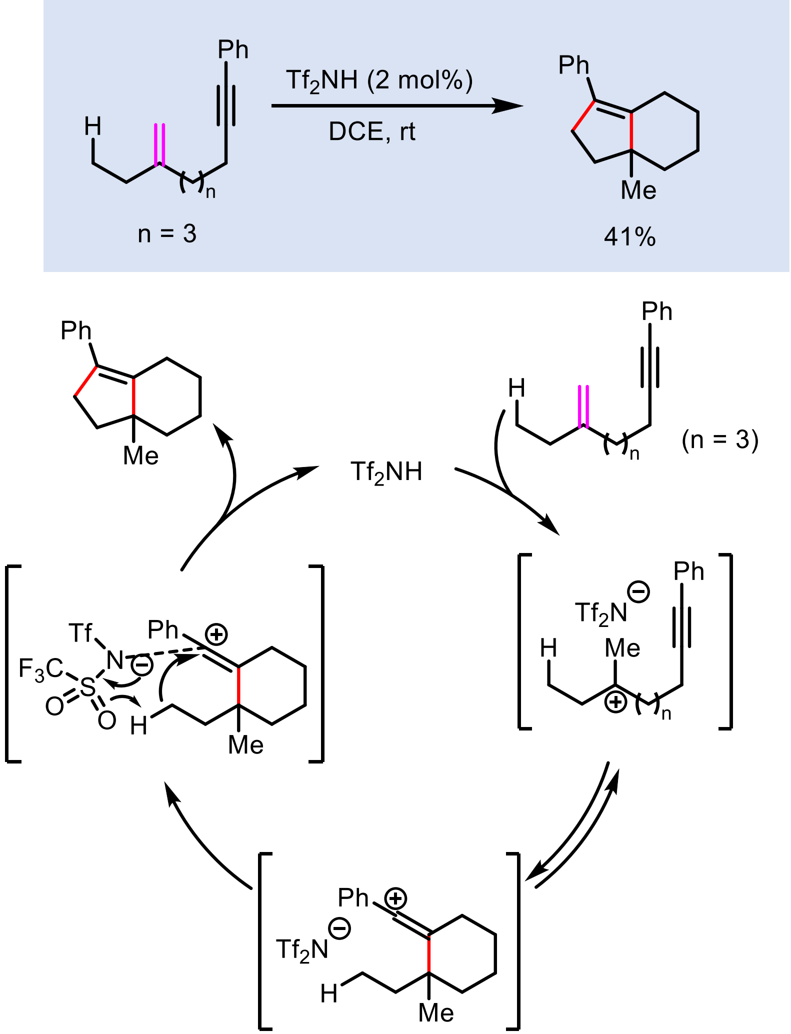


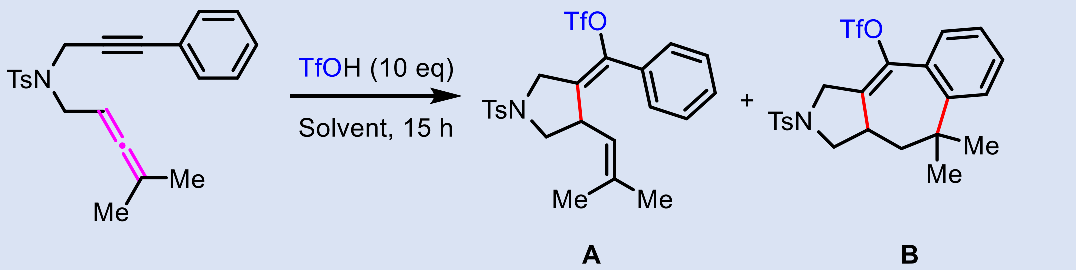


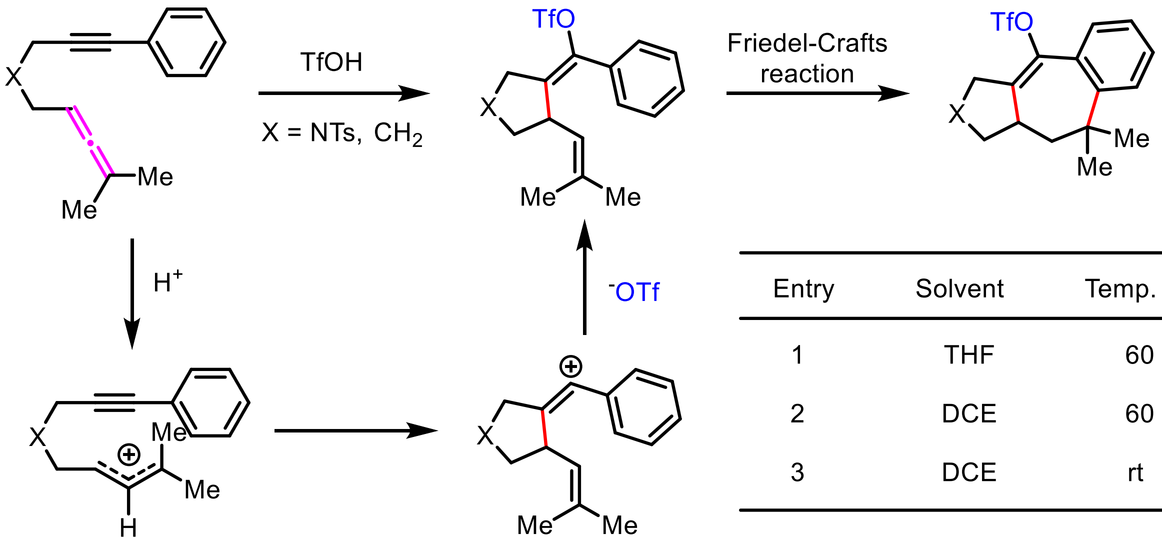
Y. Yamamoto, et. al. *Angew. Chem. Int. Ed.* **2009**, *48*, 5893–5896.

F. Rodr ǵuez, et. al. *Org. Lett.* **2018**, *20*, 1659−1662.

Ring closing reaction of alkyne with alkene and allene





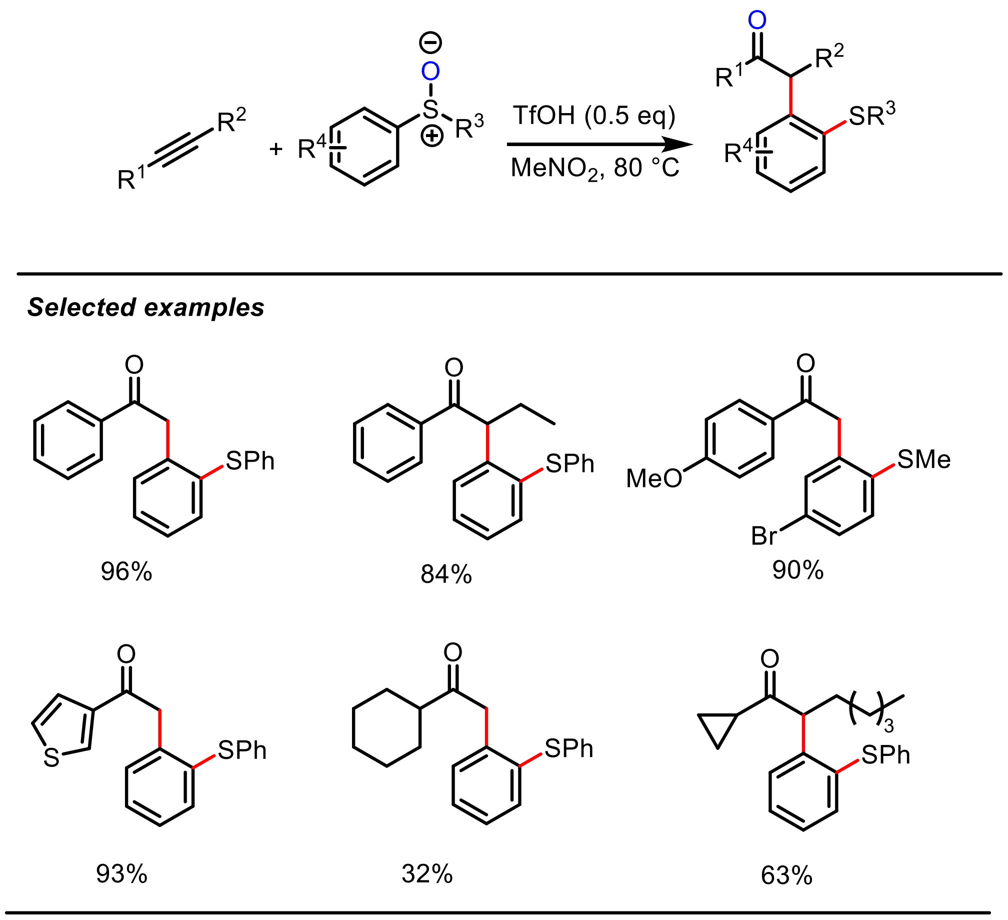


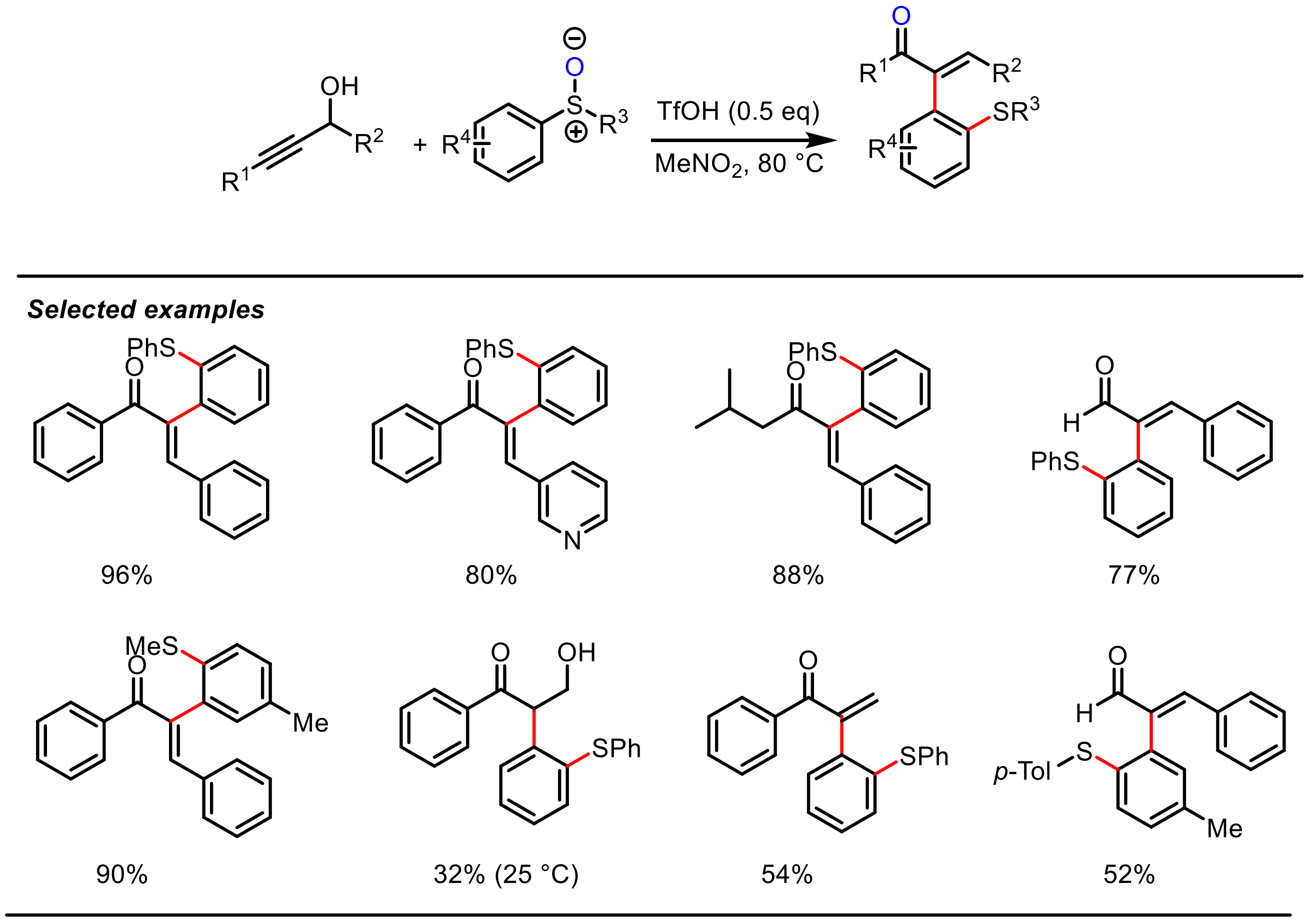
Entry	Solvent	Temp. (°C)	yield (%)
1	THF	60	trace
2	DCE	60	94(**B**)
3	DCE	rt	84(**A**)

Y. Yamamoto, et. al. *J. Am. Chem. Soc.* **2010**, *132*, 5590–5591.
Z. X. Yu, et. al. *J. Org. Chem.* **2018**, *83*, 7633−7647.

2.1 Vinyl Cations Produced by Alkynyl Group

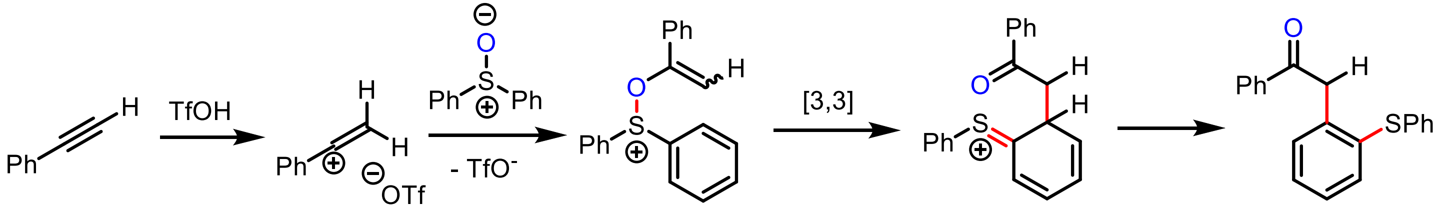
Rearrangement reaction of alkyne with sulfoxide

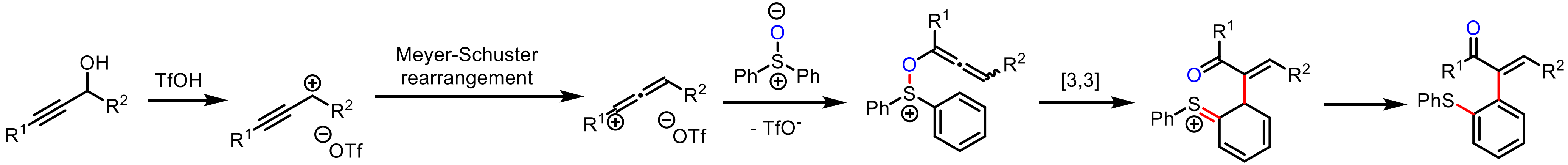


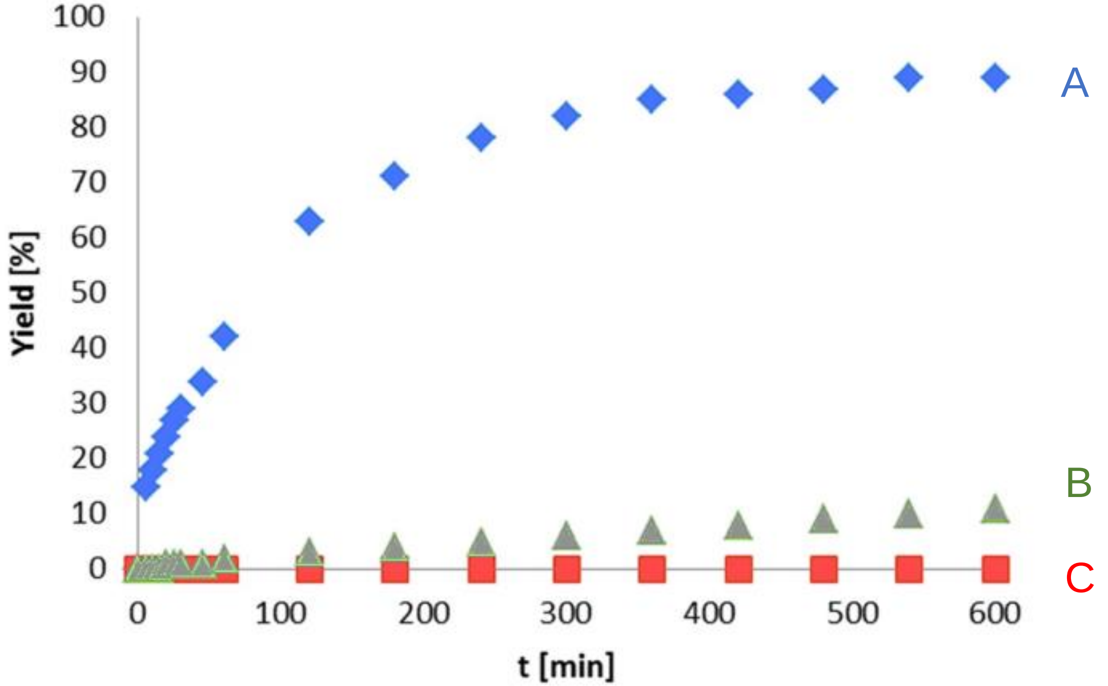


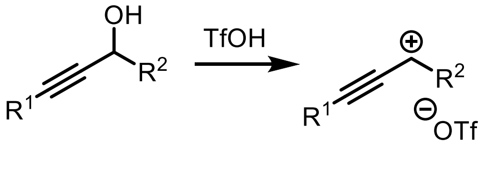
N. Maulide, et. al. *Adv. Synth. Catal*. **2017**, *359*, 64–77.

2.1 Vinyl Cations Produced by Alkynyl Group







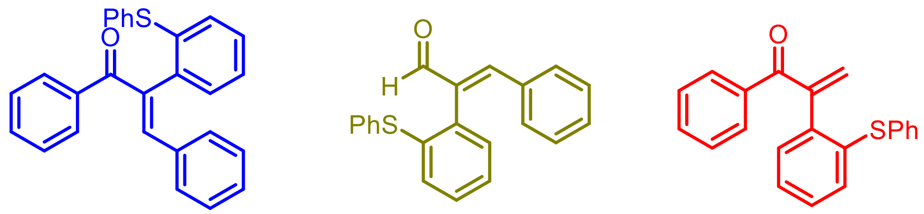


Free energy balance (kcal/mol)

A: -1.3 ($R^1 = R^2 = Ph$)

B: 5.3 ($R^1 = H, R^2 = Ph$)

C: 13.0 ($R^1 = Ph, R^2 = H$)

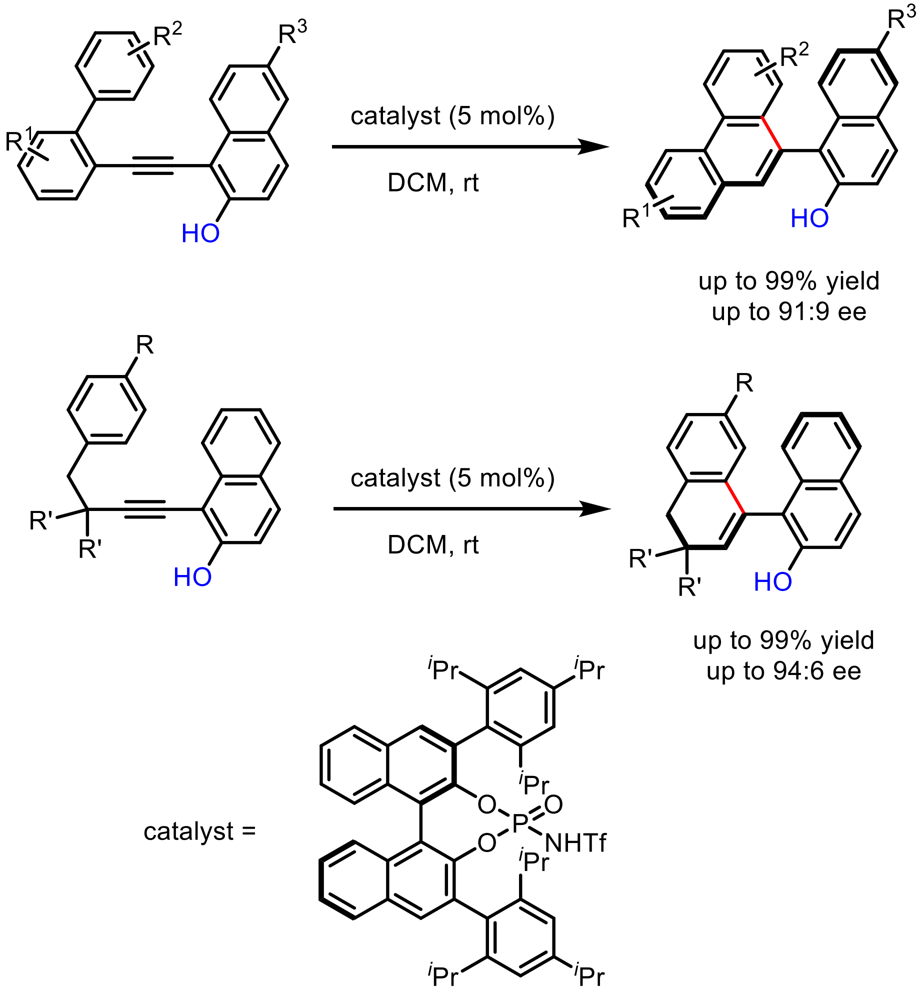


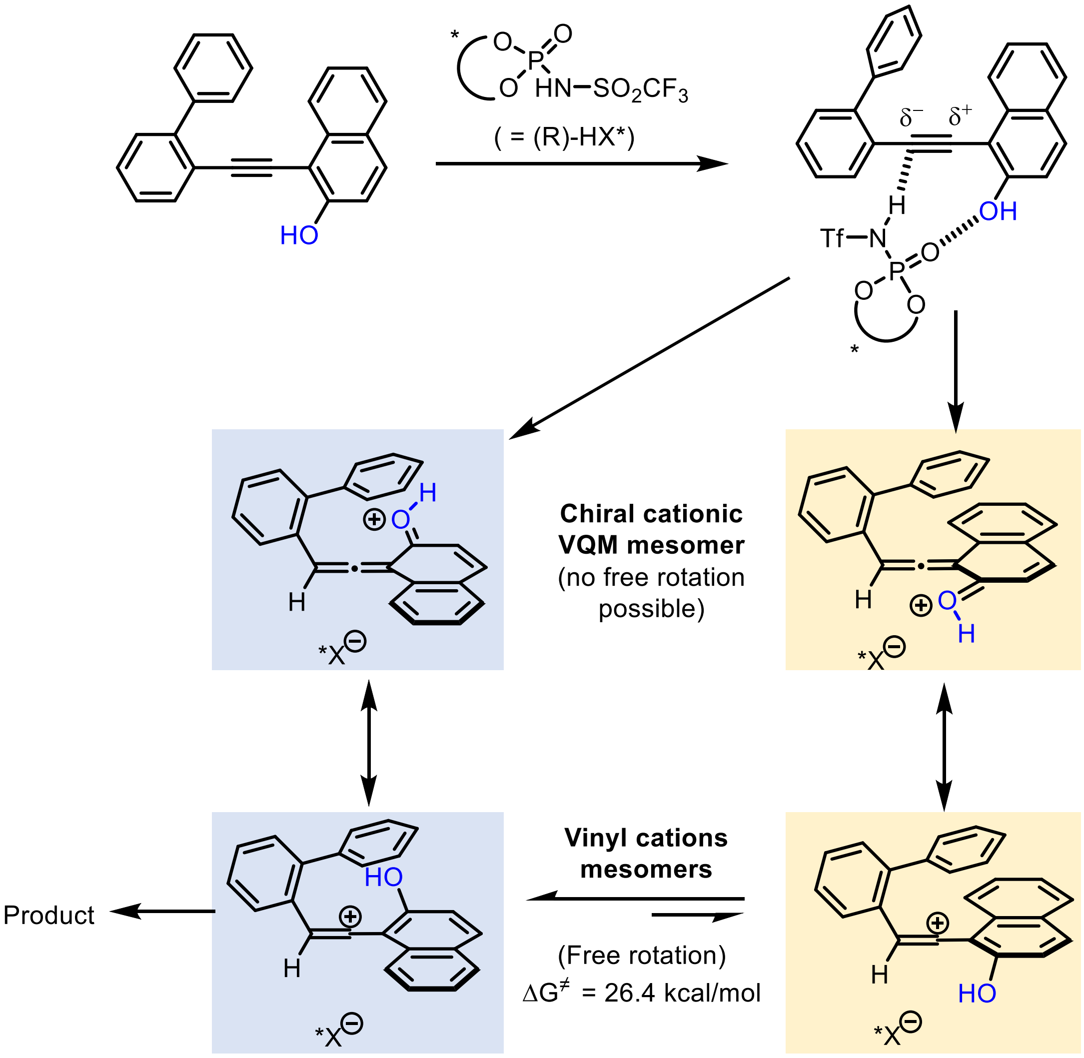
A B C

N. Maulide, et. al. *Adv. Synth. Catal.* **2017**, *359*, 64–77.

2.1 Vinyl Cations Produced by Alkynyl Group

Construction of axis chiral compounds



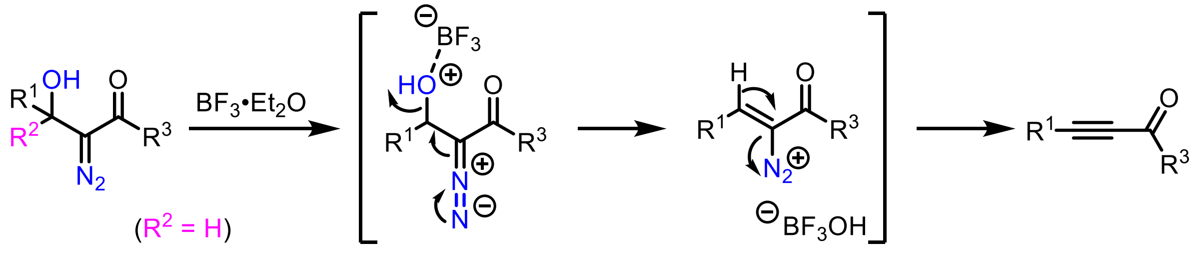


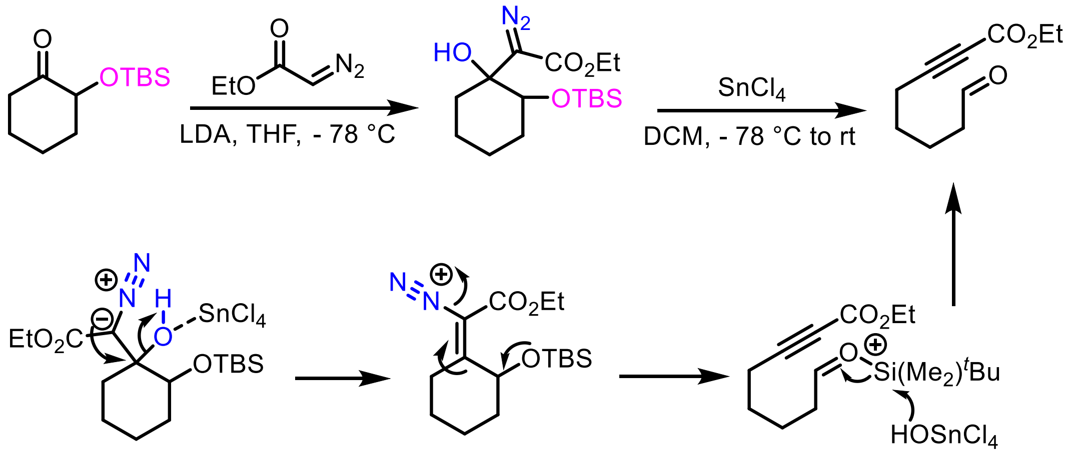
P. Y. Toullec, et. al. *Chem. Eur. J.* **2020**, *26*, 16266–16271.

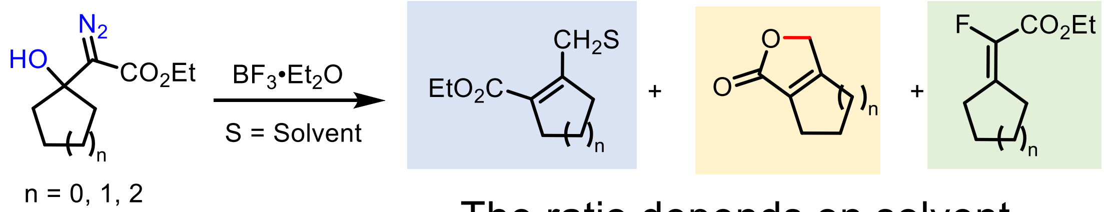
Contents

2.2 Vinyl Cations Produced by α-diazo Compounds

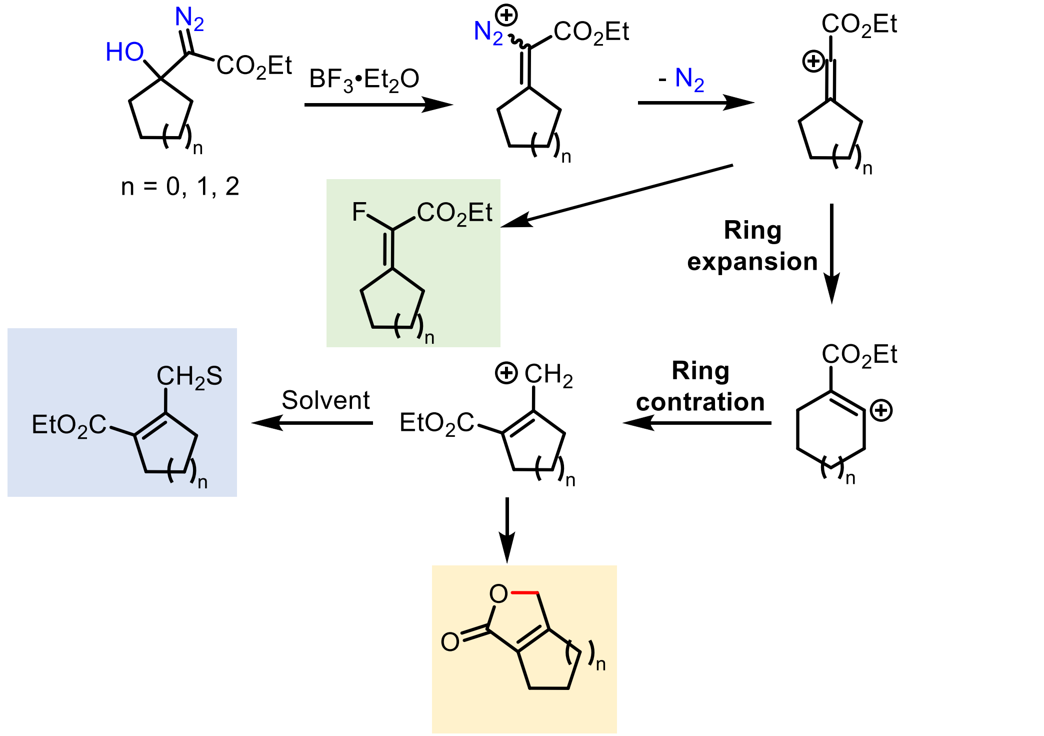
Vinyl cation by α-diazo ester







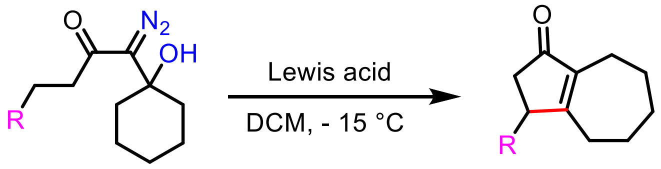
The ratio depends on solvent



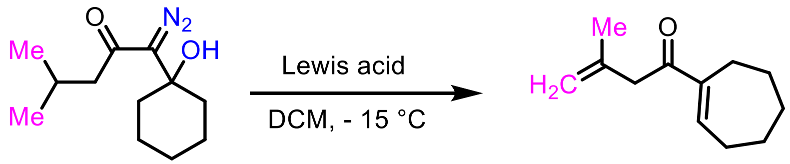
B. L. Williamson, et. al. *J. Am. Chem. Soc.* **1996**, *118*, 1-11.
M. Brewer, et. al. *J. Am. Chem. Soc.* **2008**, *130*, 3766-3767.

2.2 Vinyl Cations Produced by α-diazo Compounds

Vinyl cation by α-diazo ketone



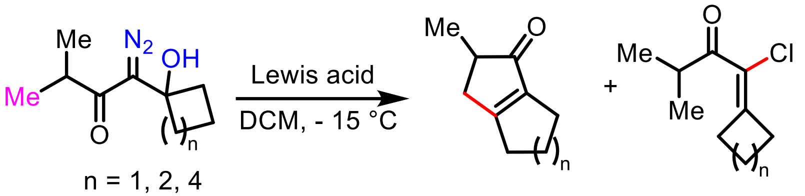
(yield: [R=H] > [R=Me])



77%

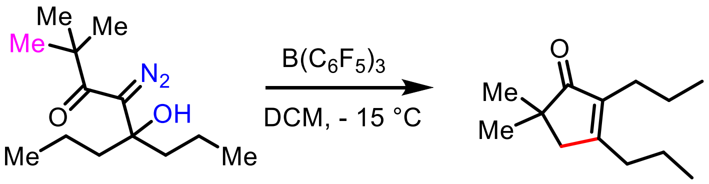
More stable carbocation

More stable carbocation to E1 elimination

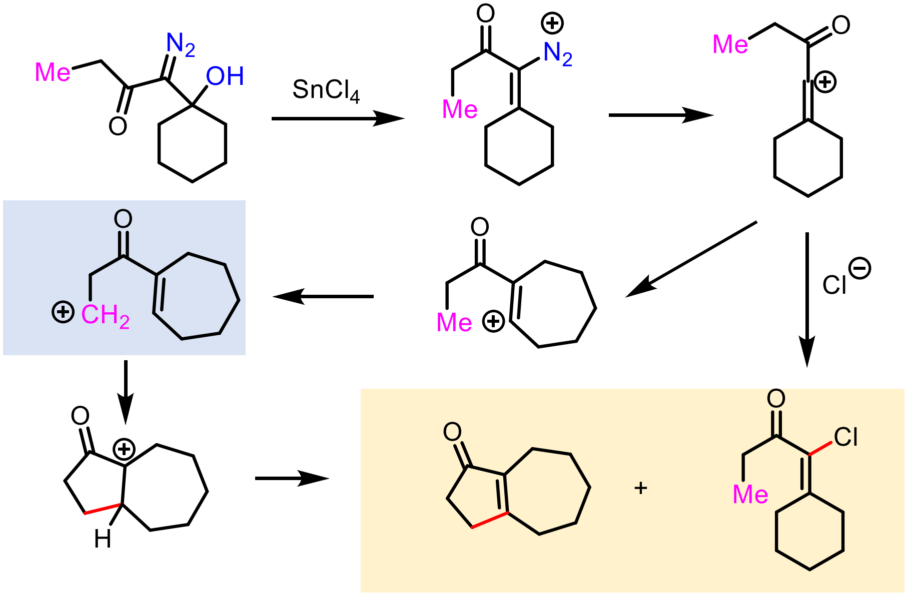


n = 1, 2, 4

ratio depends on lewis acid



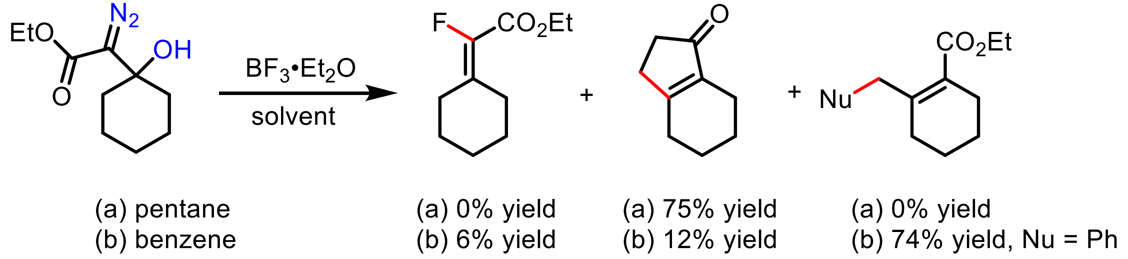
63%



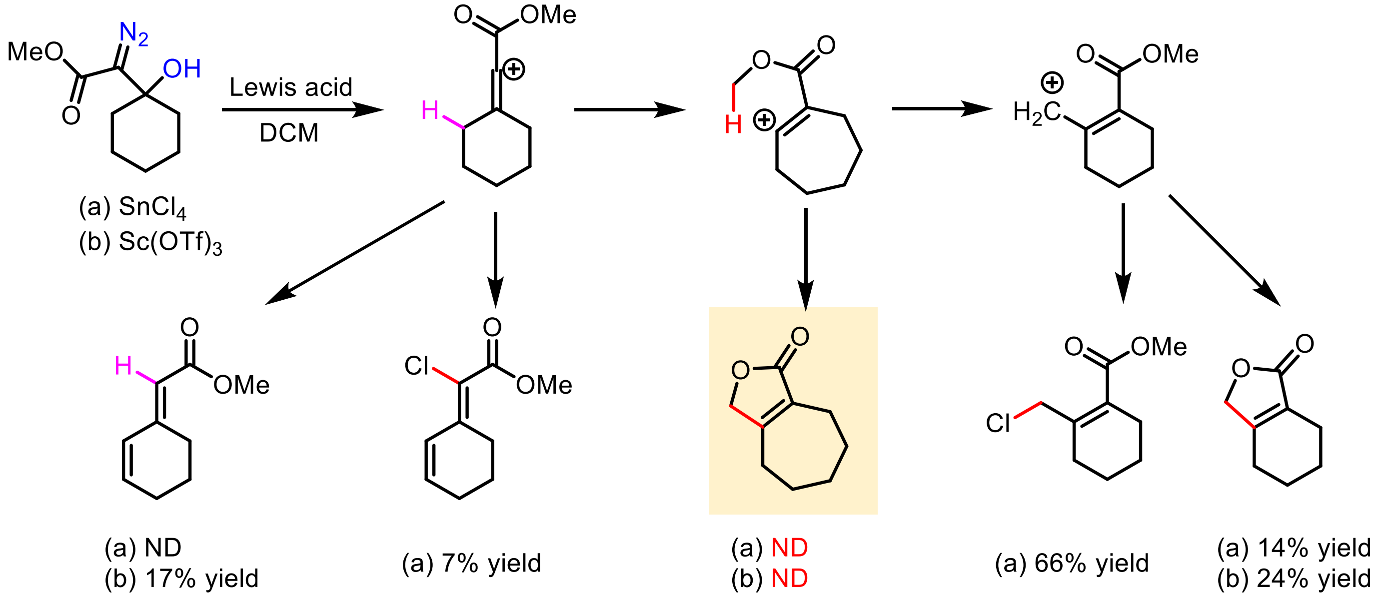
M. Brewer, et. al. *Chem. Sci.* **2017**, *8*, 6810–6814.

2.2 Vinyl Cations Produced by α-diazo Compounds

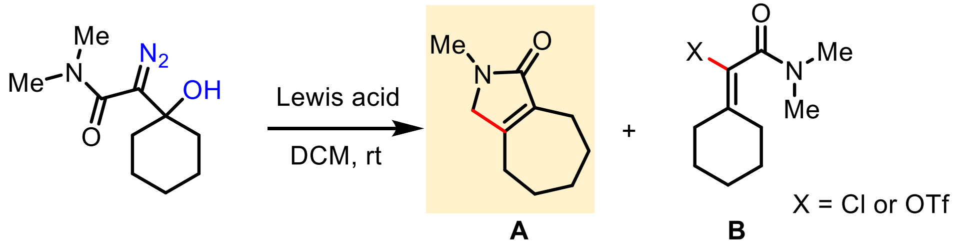
Vinyl cation by α-diazo amide



Different solvent gives different ratio



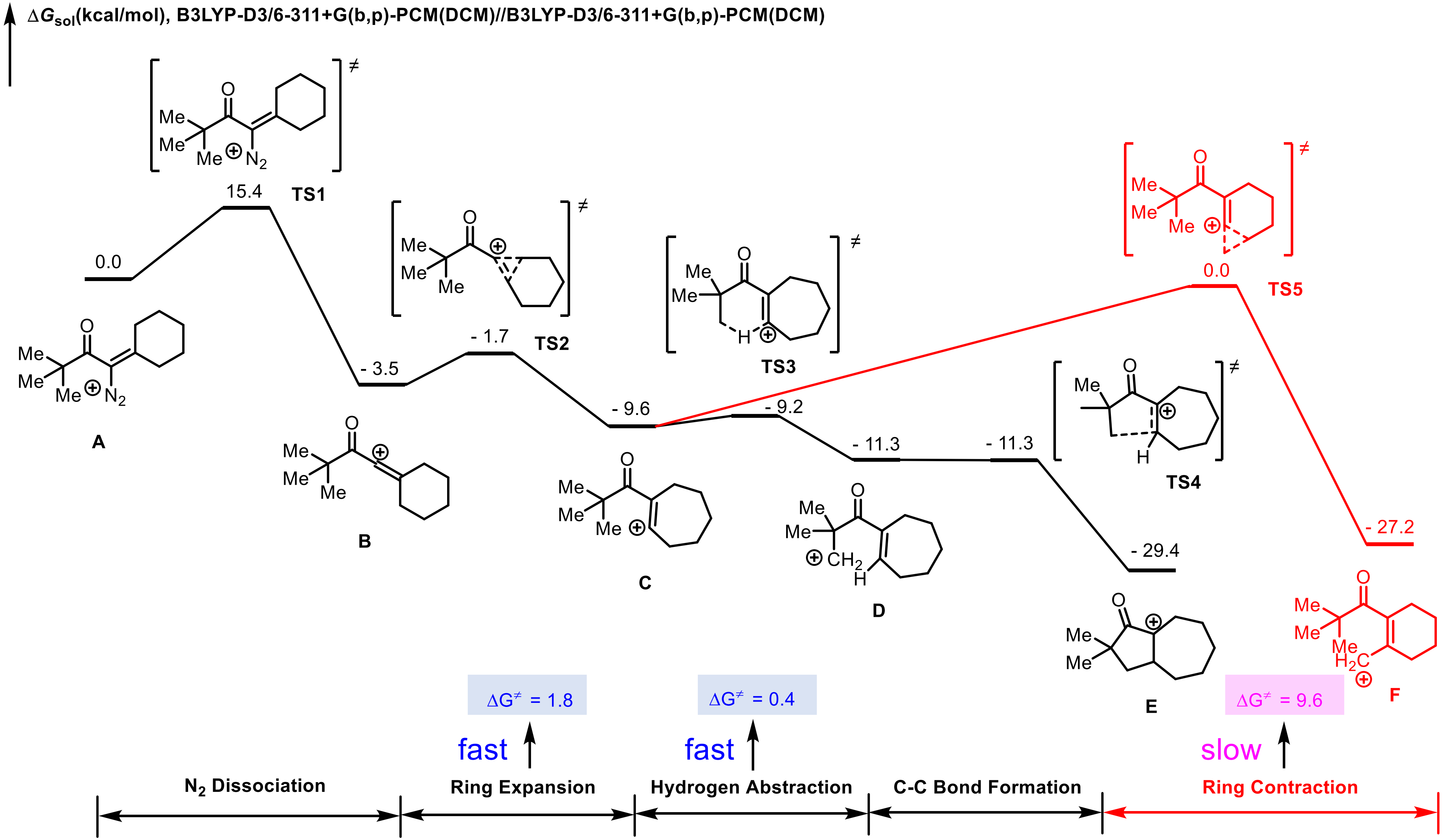
Different lewis acid gives different ratio



Entry	Lewis acid	Yield **A**	Yield **B**
1	$B(C_6F_5)_3$	ND	ND
2	$SnCl_4$	trace	33%
3	$Sc(OTf)_3$	24%	25%
4	$In(OTf)_3$	17%	28%
5	TMSOTf	6%	62%

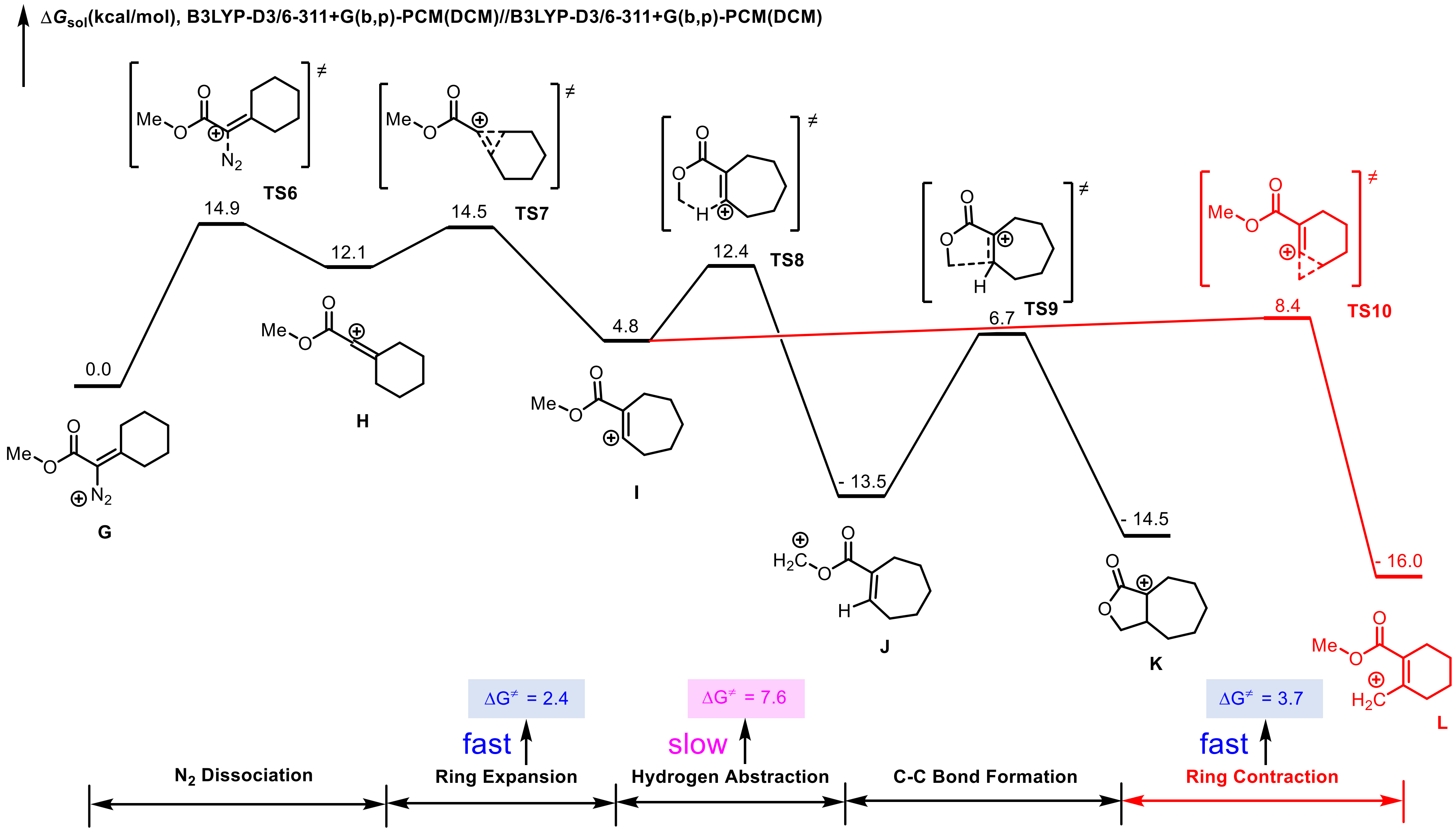
M. Brewer, et. al. *J. Am. Chem. Soc.* **2019**, *141*, 3558−3565.

2.2 Vinyl Cations Produced by α-diazo Compounds



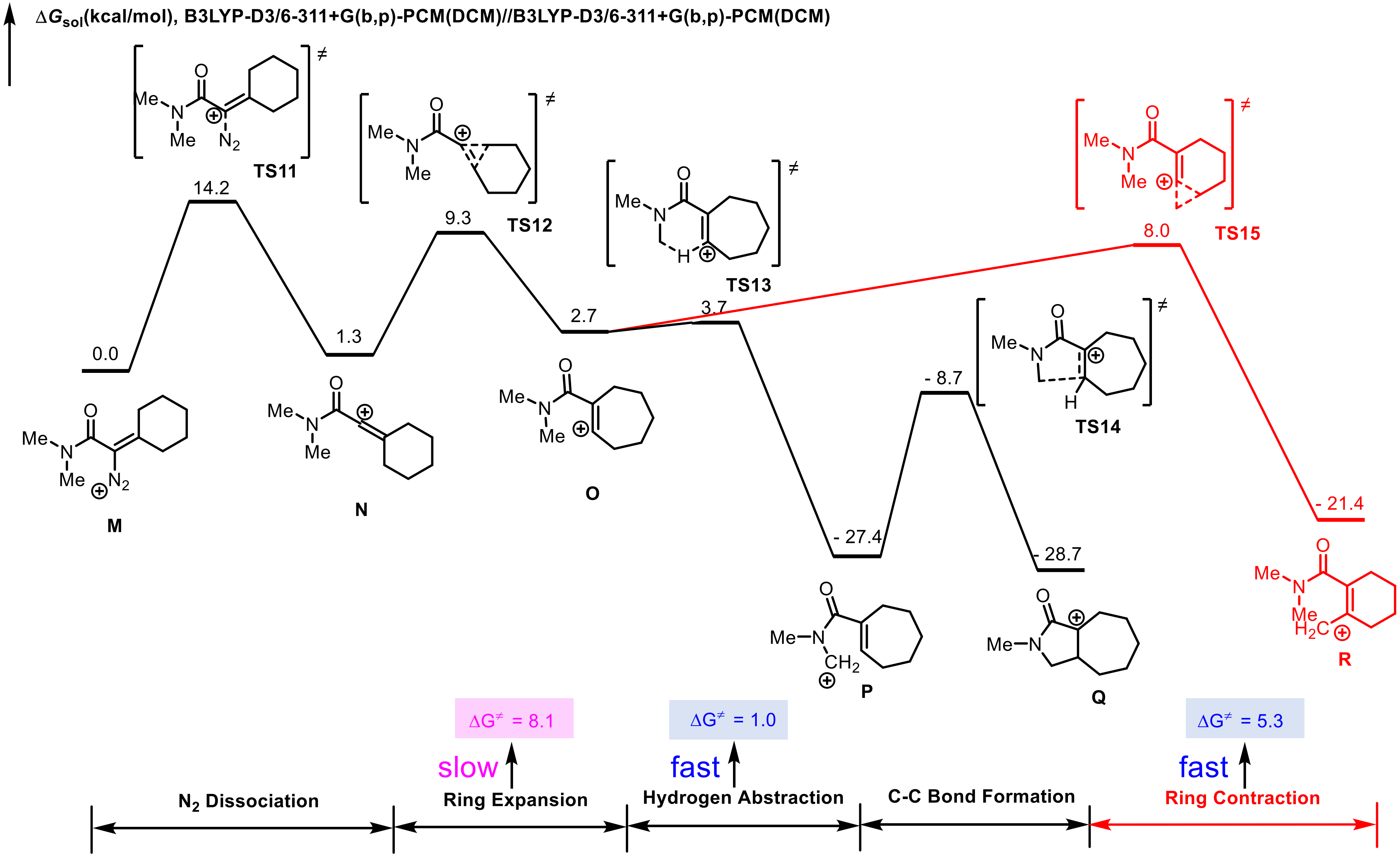
M. Brewer, et. al. *J. Am. Chem. Soc.* **2019**, *141*, 3558−3565.

2.2 Vinyl Cations Produced by α-diazo Compounds



M. Brewer, et. al. *J. Am. Chem. Soc.* **2019**, *141*, 3558−3565.

2.2 Vinyl Cations Produced by α-diazo Compounds

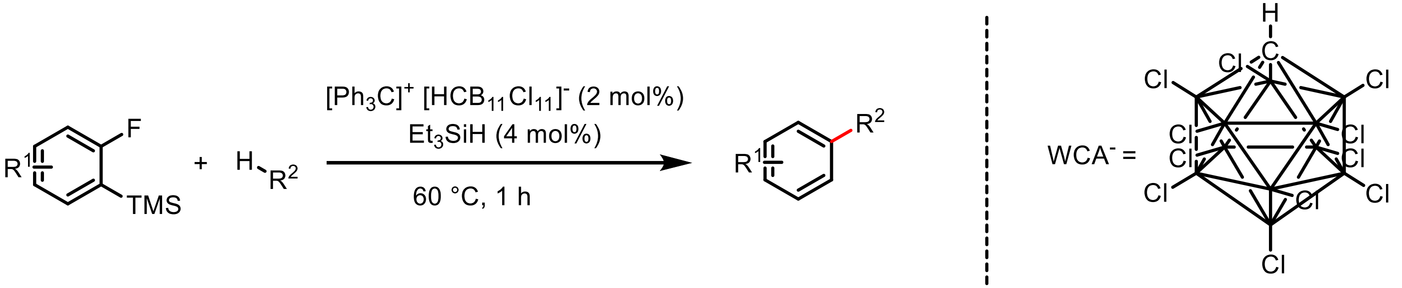


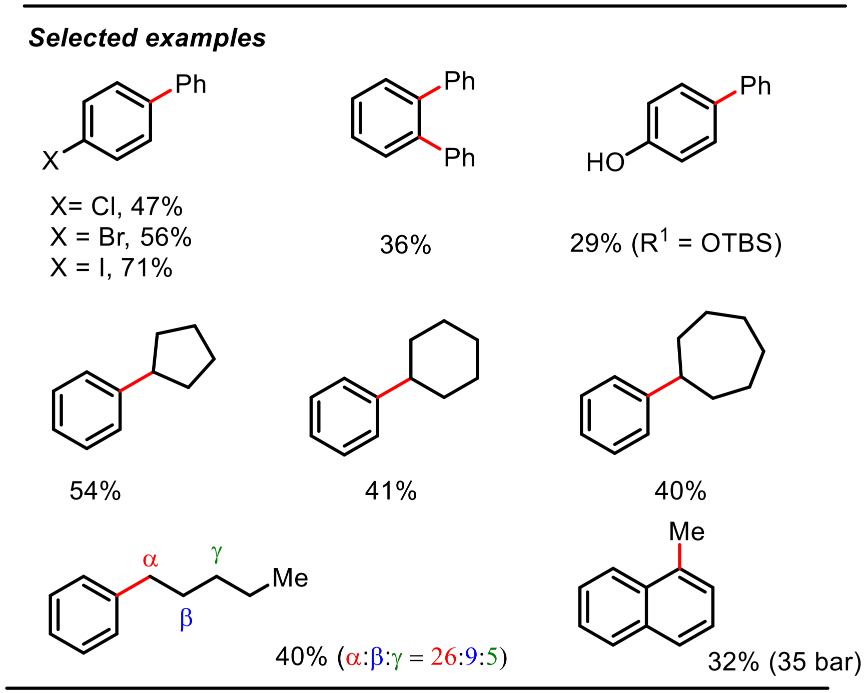
M. Brewer, et. al. *J. Am. Chem. Soc.* **2019**, *141*, 3558−3565.

Contents

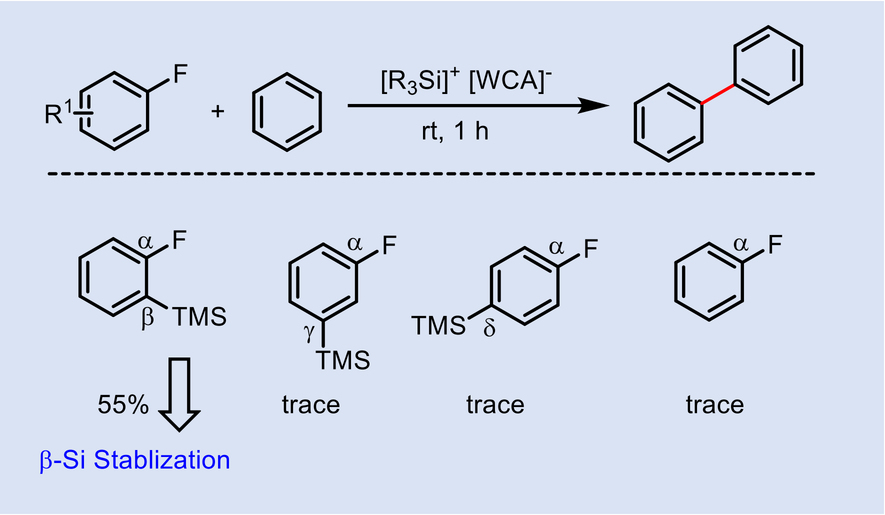
2.3 Vinyl Cations Produced in Situ by Vinyl Compounds

Aryl Cation





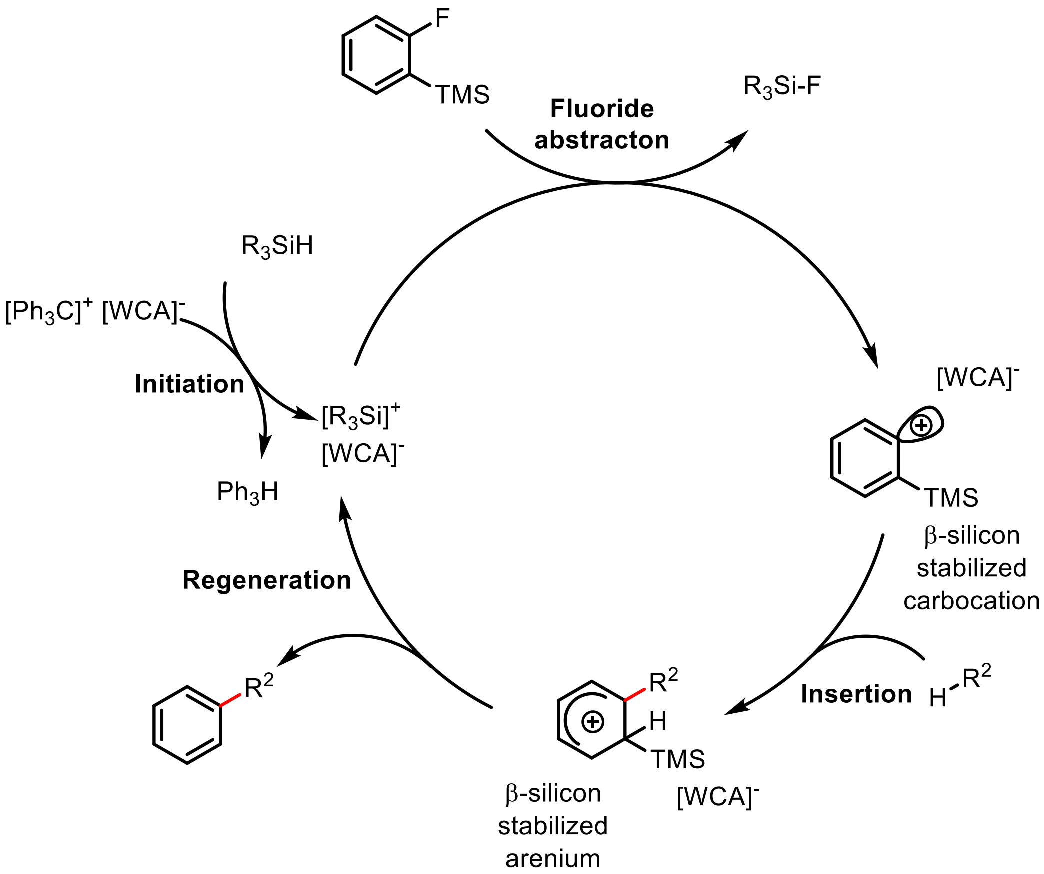
The role of β-Si group

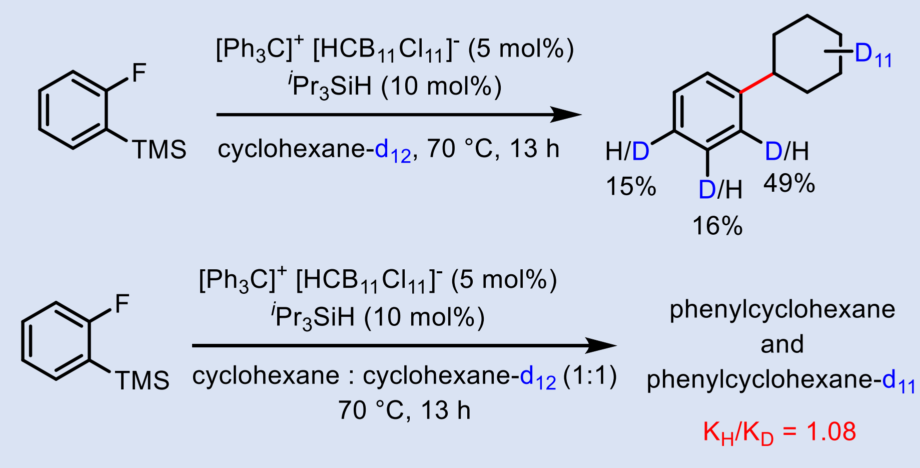


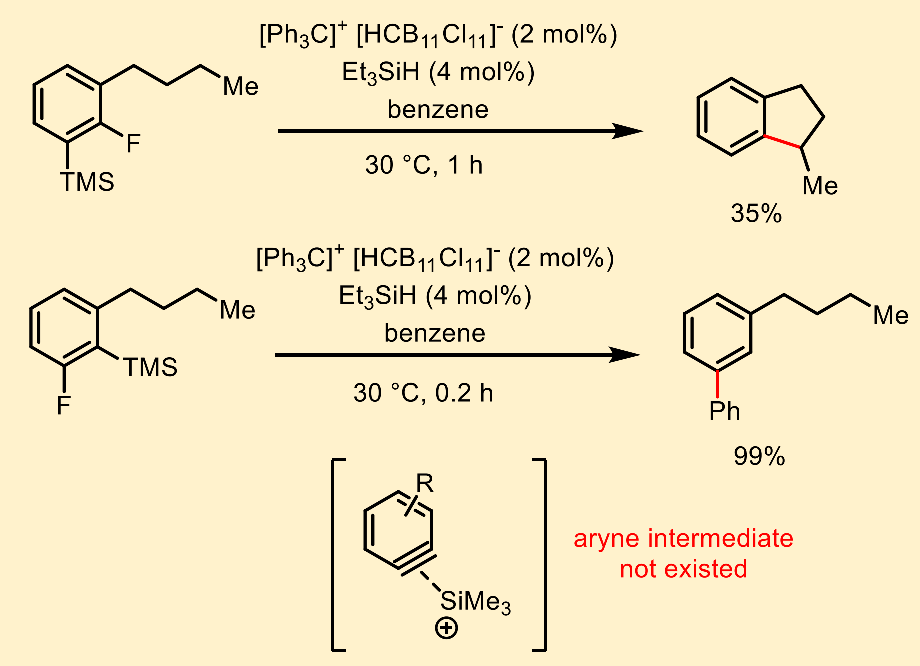
H. M. Nelson, et. al. *Science*. **2017**, *355*, 1403–1407.

2.3 Vinyl Cations Produced in Situ by Vinyl Compounds

Aryl Cation

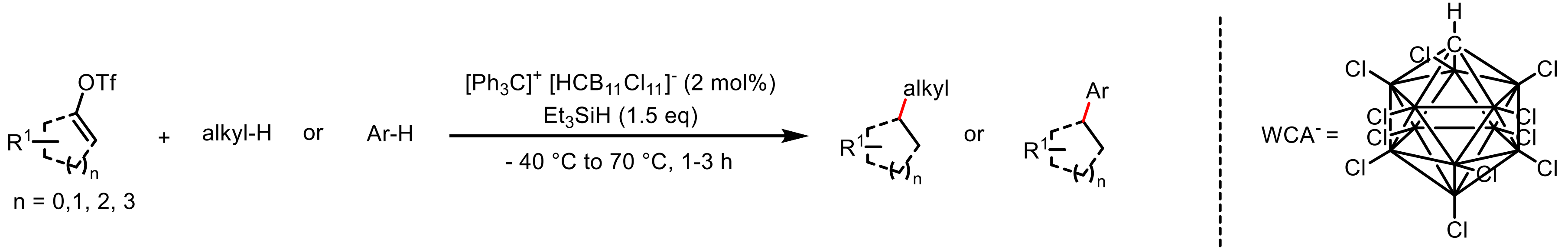


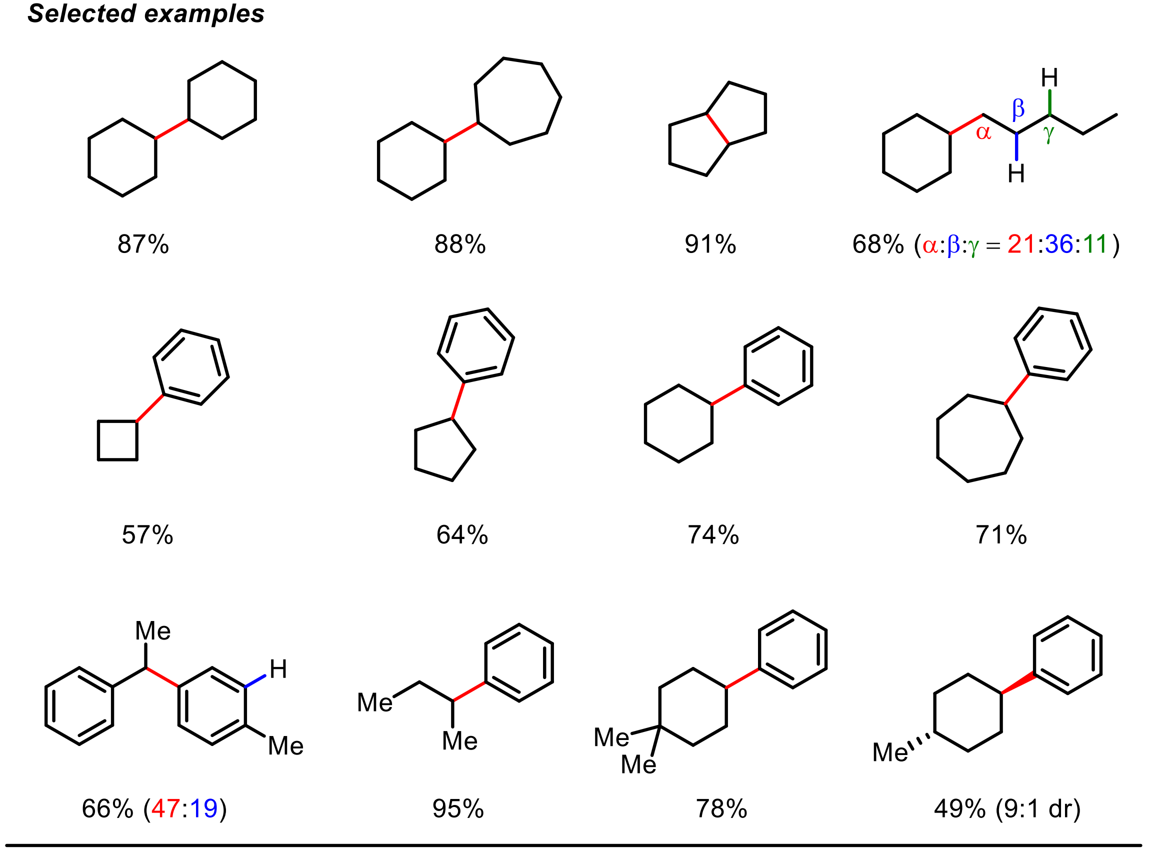


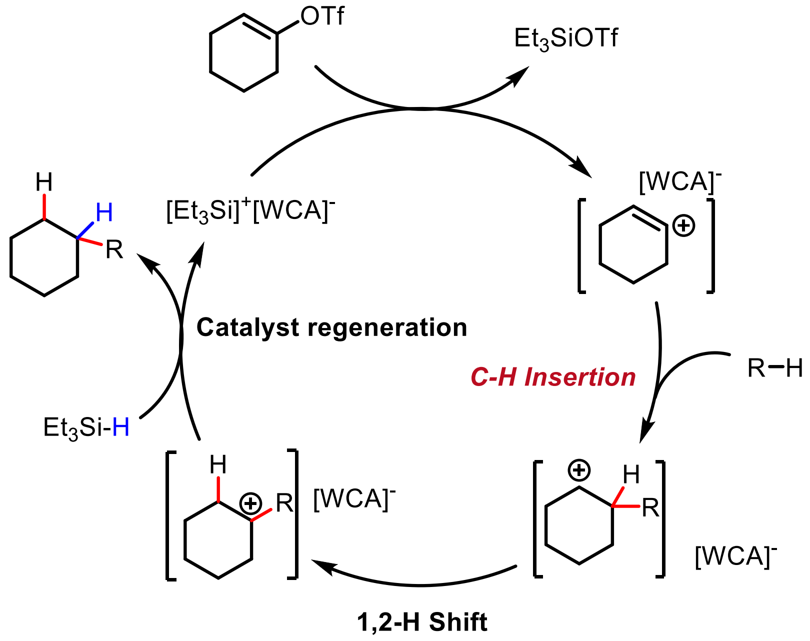


H. M. Nelson, et. al. *Science*. **2017**, *355*, 1403–1407.

2.3 Vinyl Cations Produced in Situ by Vinyl Compounds



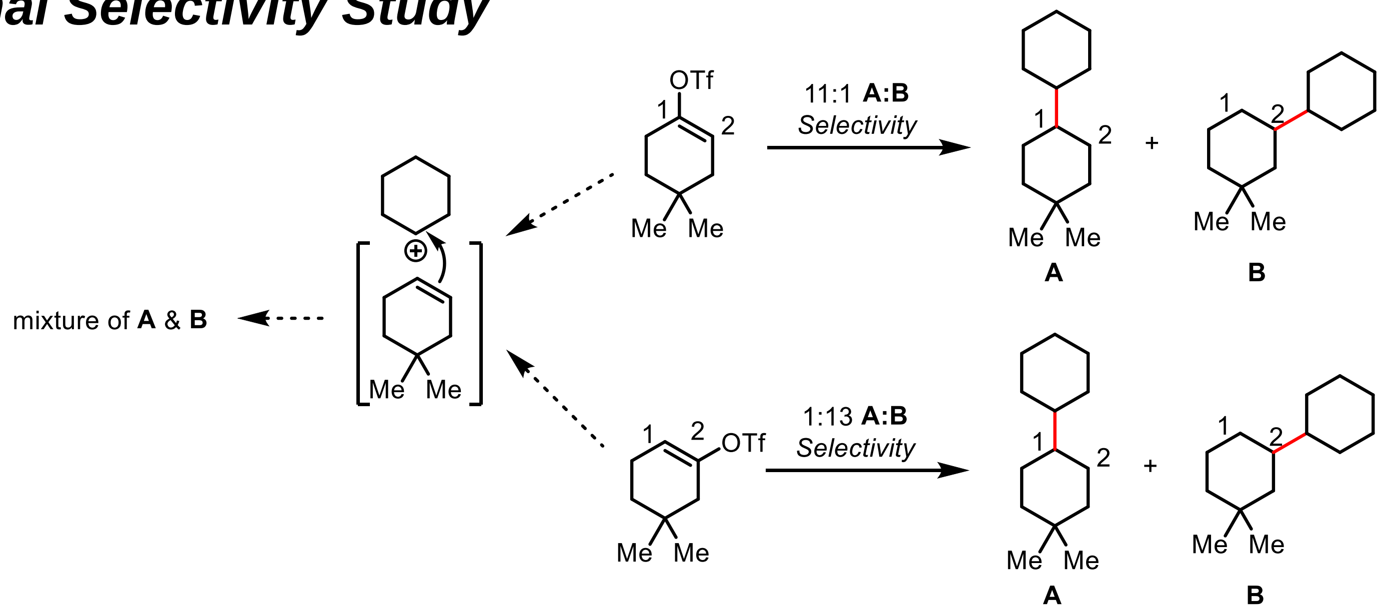




C-H insertion: concerted vs stepwise

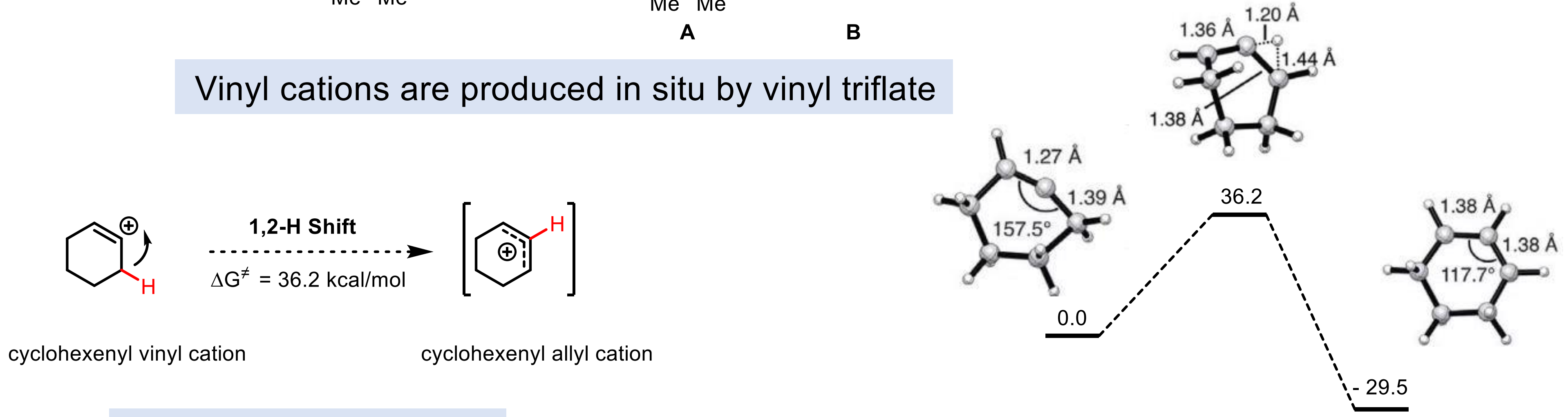
K. N. Houk, H. M. Nelson, et. al. *Science*, **2018**, *361*, 381–387.

Regional Selectivity Study



Experimental ratio	MD ratio
11:1 (**A**:**B**)	50:7 (**A**:**B**)
1:13 (**A**:**B**)	9:46 (**A**:**B**)

Vinyl cations are produced in situ by vinyl triflate

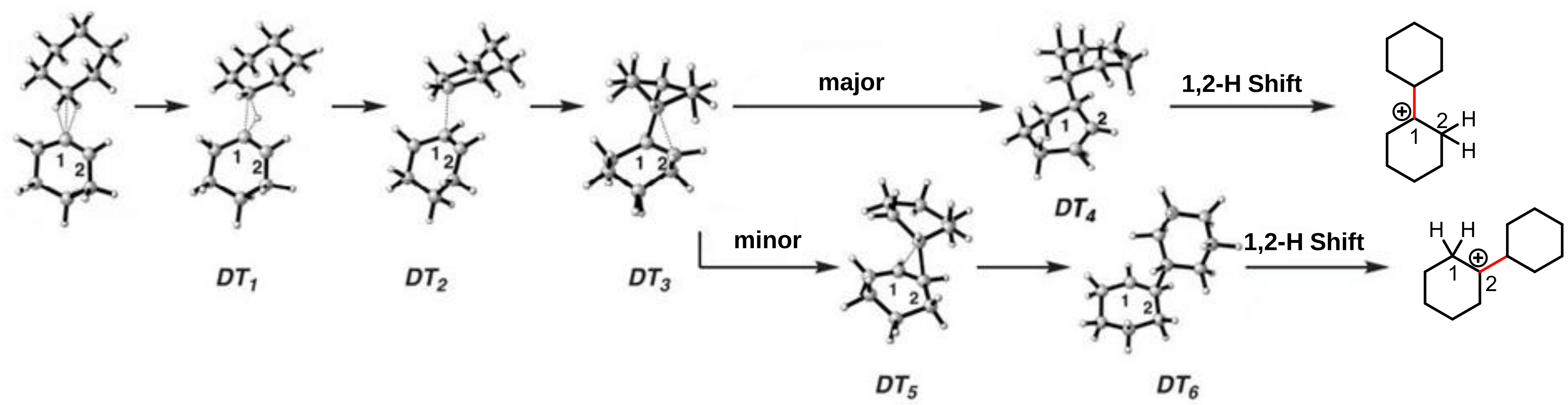


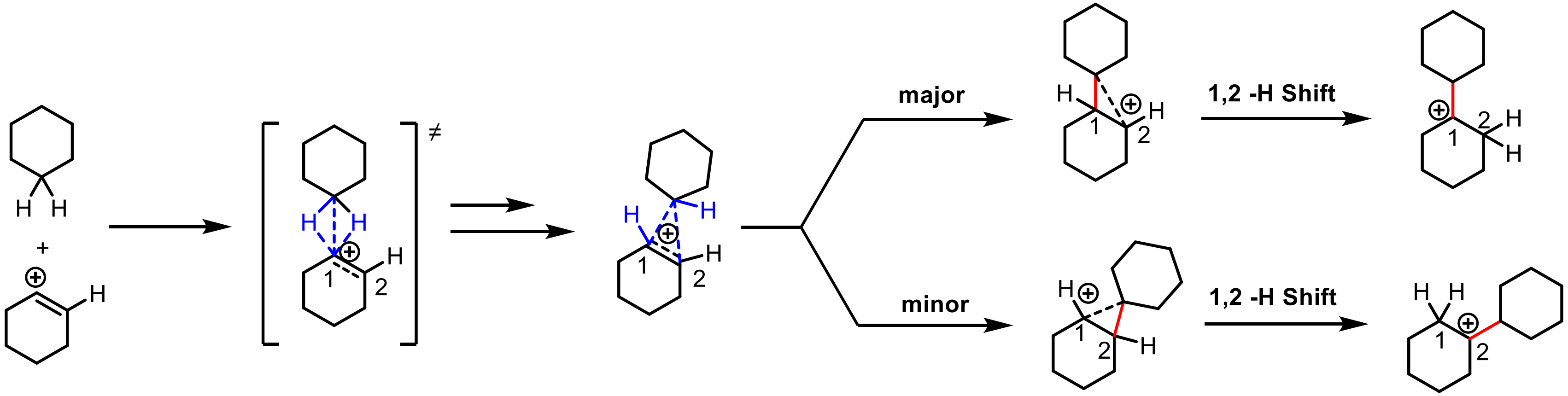
1,2-H shift is impossible

K. N. Houk, H. M. Nelson, et. al. *Science*, **2018**, *361*, 381–387.

2.3 Vinyl Cations Produced in Situ by Vinyl Compounds

Mechanism for C-H Insertion



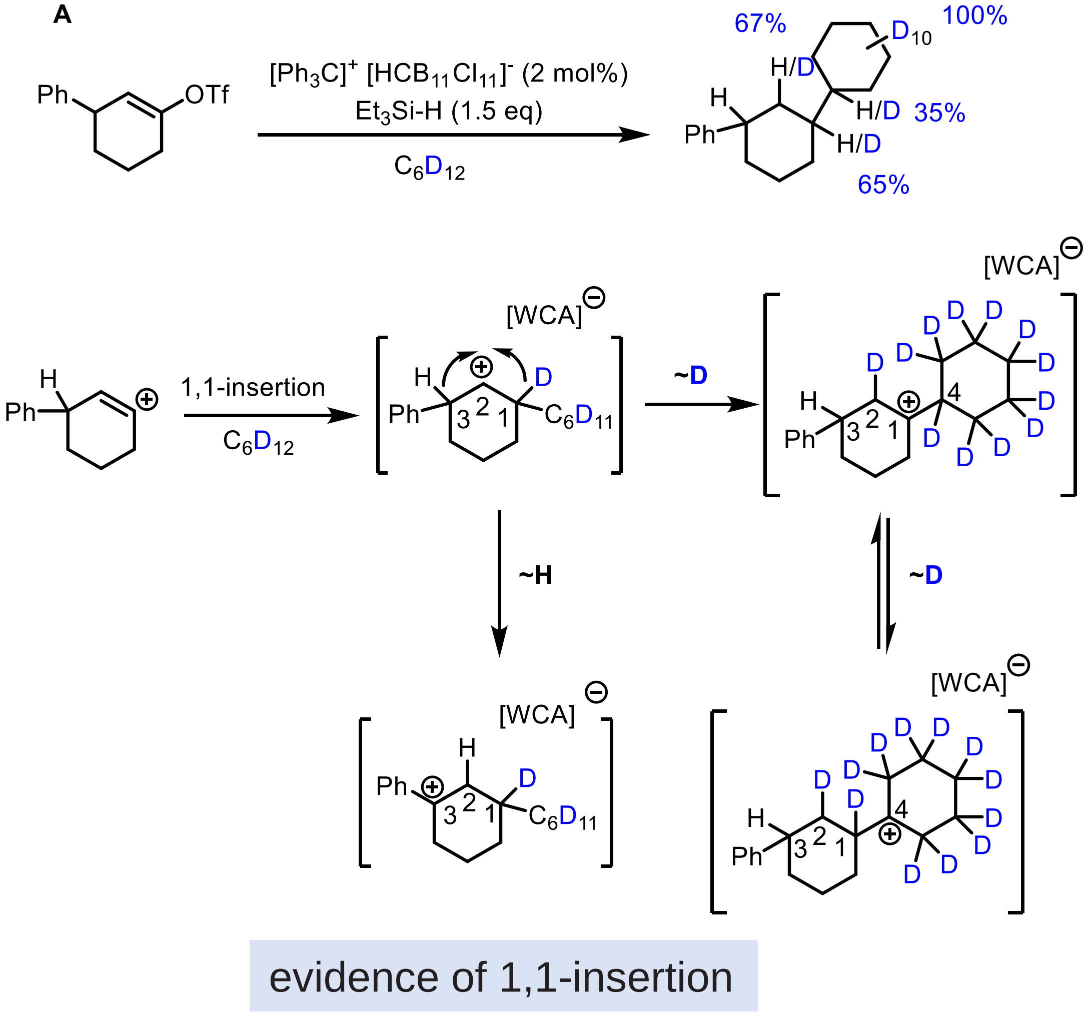


K. N. Houk, H. M. Nelson, et. al. *Science*, **2018**, *361*, 381–387.

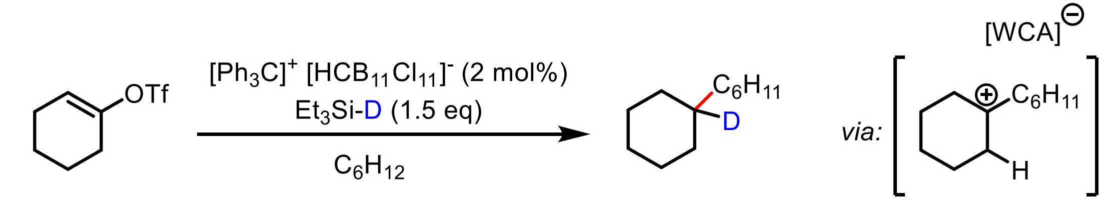
2.3 Vinyl Cations Produced in Situ by Vinyl Compounds

Isotopic Labeling Studies

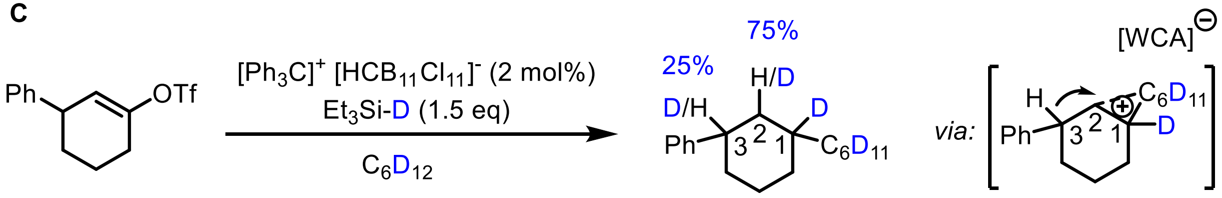
A



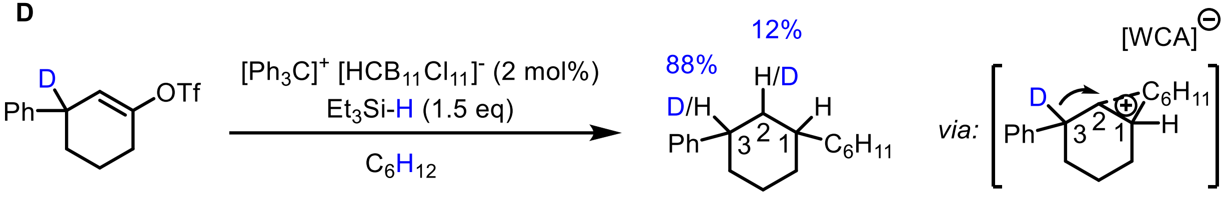
B



C



D



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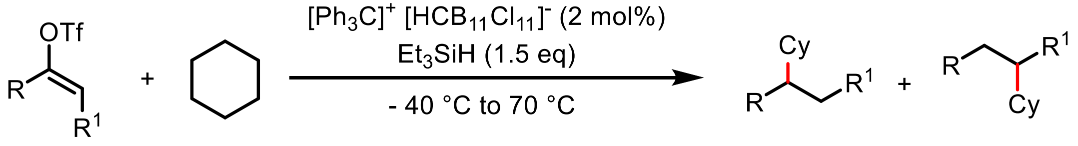
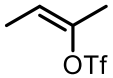
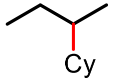
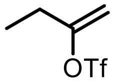
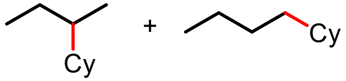
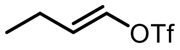
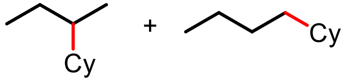
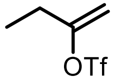
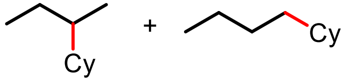
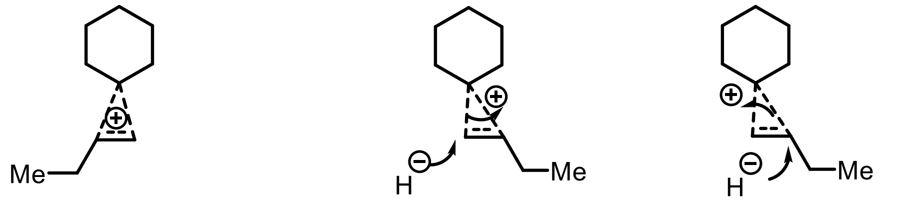
2.3 Vinyl Cations Produced in Situ by Vinyl Compounds



Entry	Substrate	Solvent	Temp. (°C)	Product
1		C_6H_{12}	30	 85%
2		C_6H_{12}	30	 40% + 39%
3		C_6H_{12}	70	 16% + 19%
4		$CHCl_3/C_6H_{12}$	-40	 17% + 34%

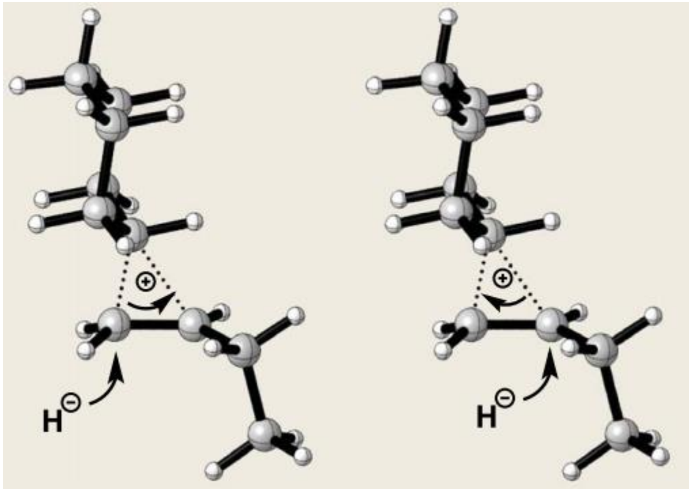
$CHCl_3$: attenuate hyperconjugative effects of cyclohexene



unsymmetrically bridged nonclassical ion

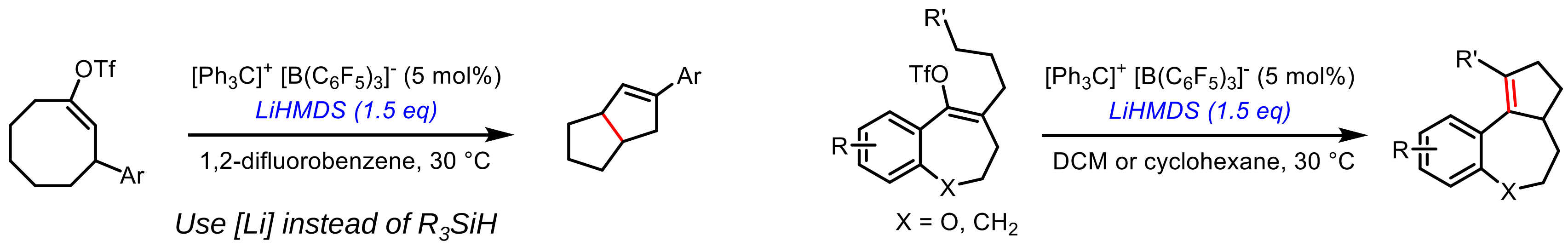
hydride approach leading to branch

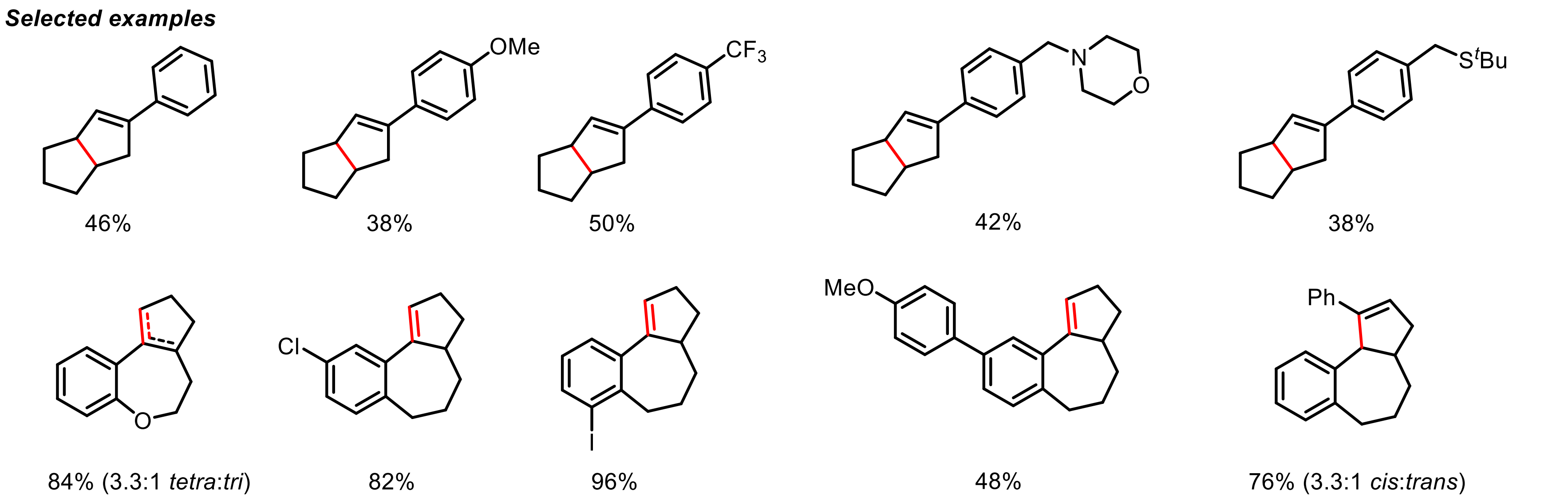
hydride approach leading to end



K. N. Houk, H. M. Nelson, et. al. *Science*, **2018**, *361*, 381–387.

2.3 Vinyl Cations Produced in Situ by Vinyl Compounds

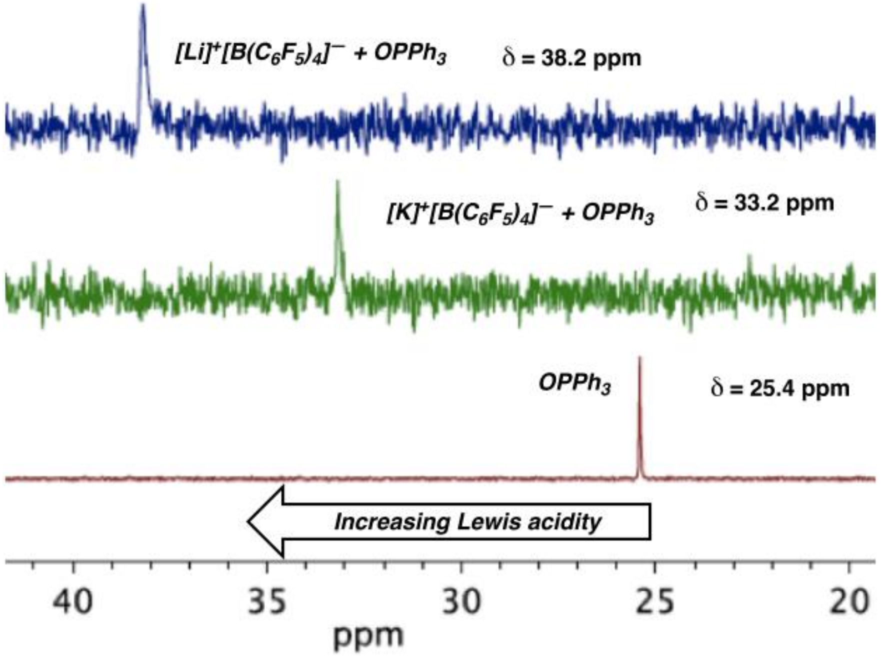




K. N. Houk, H. M. Nelson, et. al. *J. Am. Chem. Soc.* **2019**, *141*, 9140–9144.

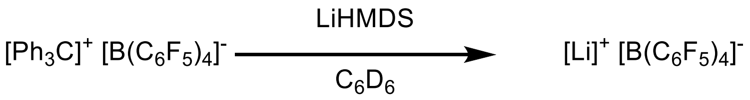
2.3 Vinyl Cations Produced in Situ by Vinyl Compounds

A Gutmann-Beckett ^{31}P NMR studies

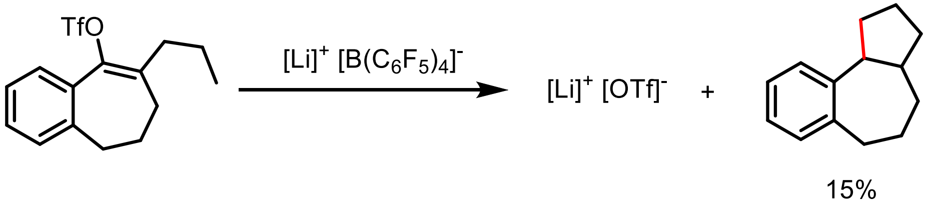


The yield: [Li] > [Na] > [K]
The reactivity: [Li] > [Na] > [K]

B Generation of $[Li]^+ [B(C_6F_5)_4]^-$ under reaction condition



C Stoichiometric triflate abstraction



Catalysis: $[Li]^+ [B(C_6F_5)_4]^-$

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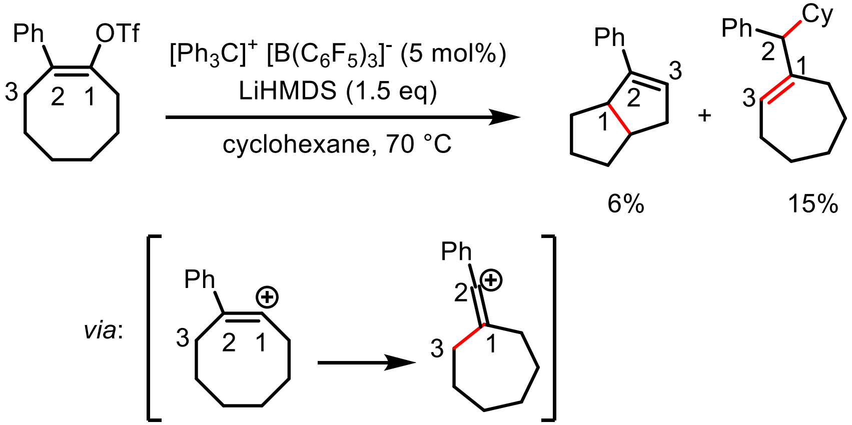
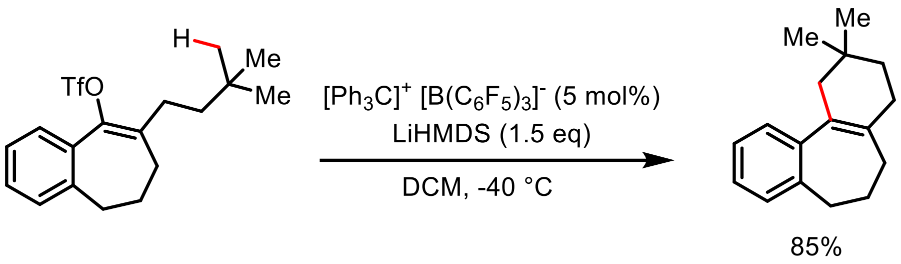
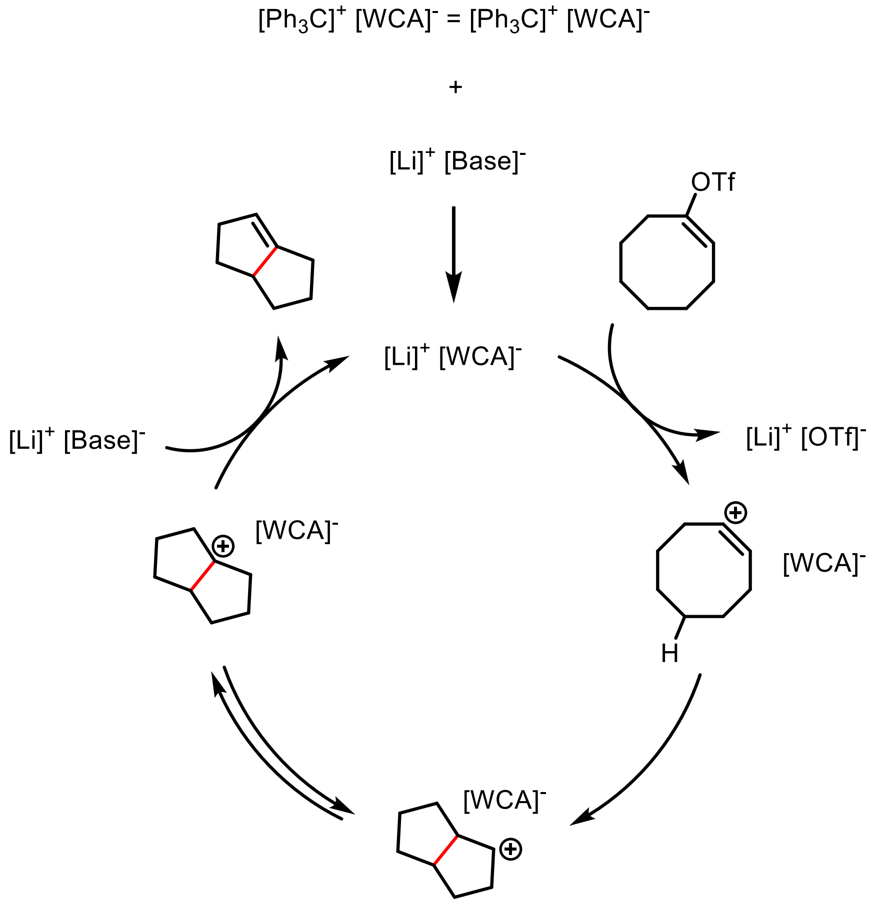
2.3 Vinyl Cations Produced in Situ by Vinyl Compounds

D Evidence of a vinyl cation intermediate



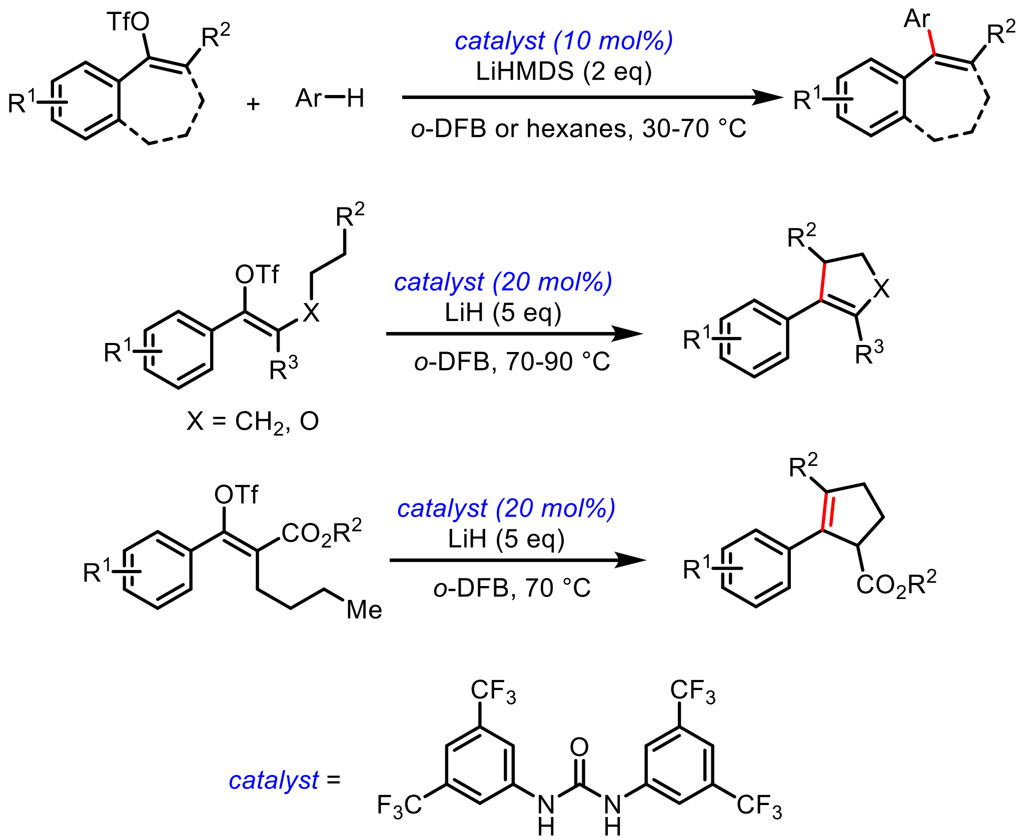
E Evidence supporting concerted C-H insertion

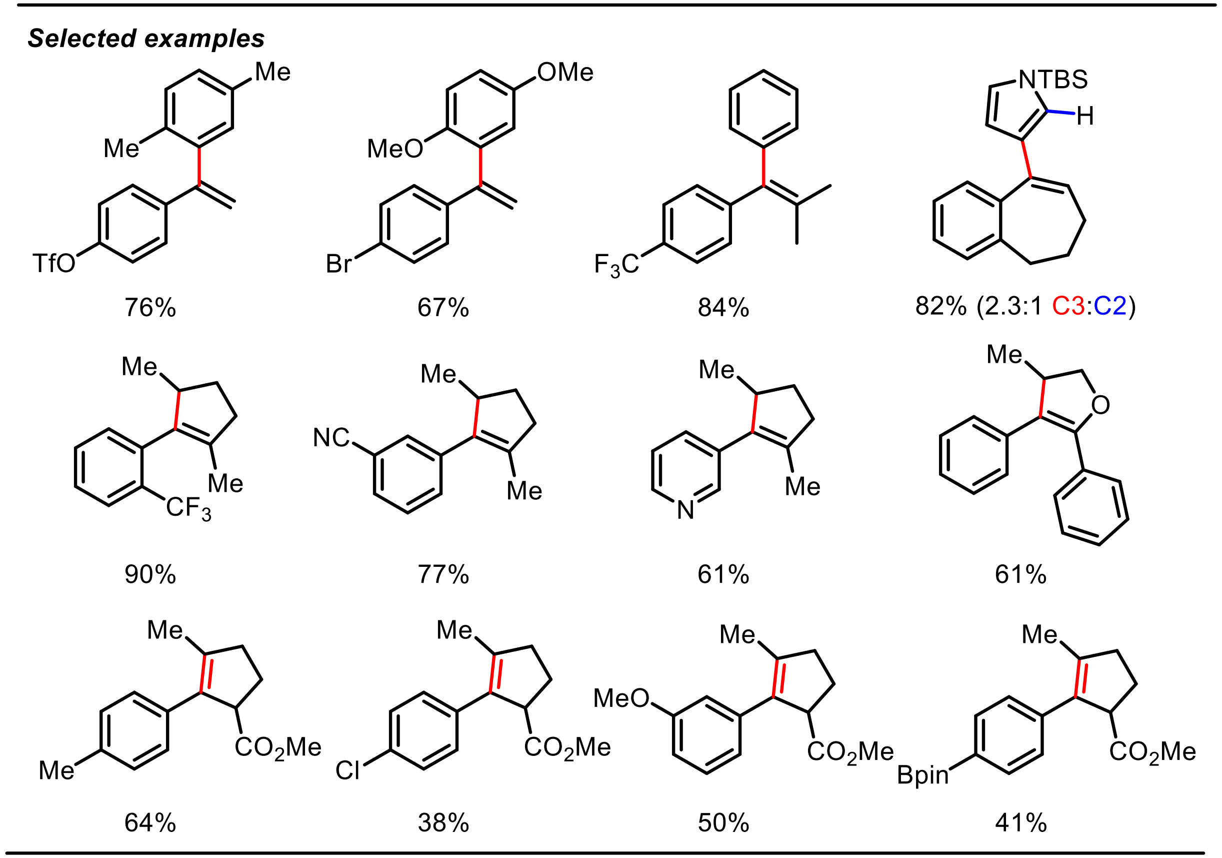




K. N. Houk, H. M. Nelson, et. al. *J. Am. Chem. Soc.* **2019**, *141*, 9140−9144.

2.3 Vinyl Cations Produced in Situ by Vinyl Compounds

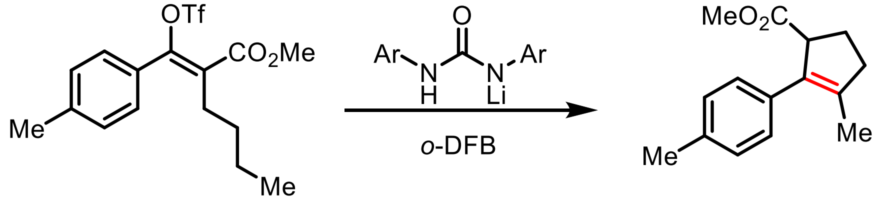




H. M. Nelson, et. al. *Org. Lett.* **2020**, *22*, 7775−7779.

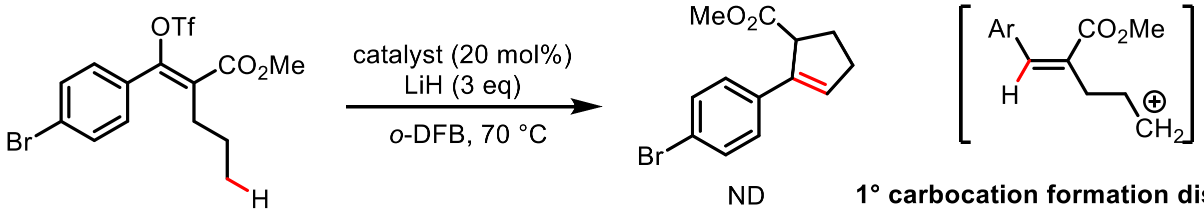
2.3 Vinyl Cations Produced in Situ by Vinyl Compounds

A Stoichiometric experiments with lithium urea salt



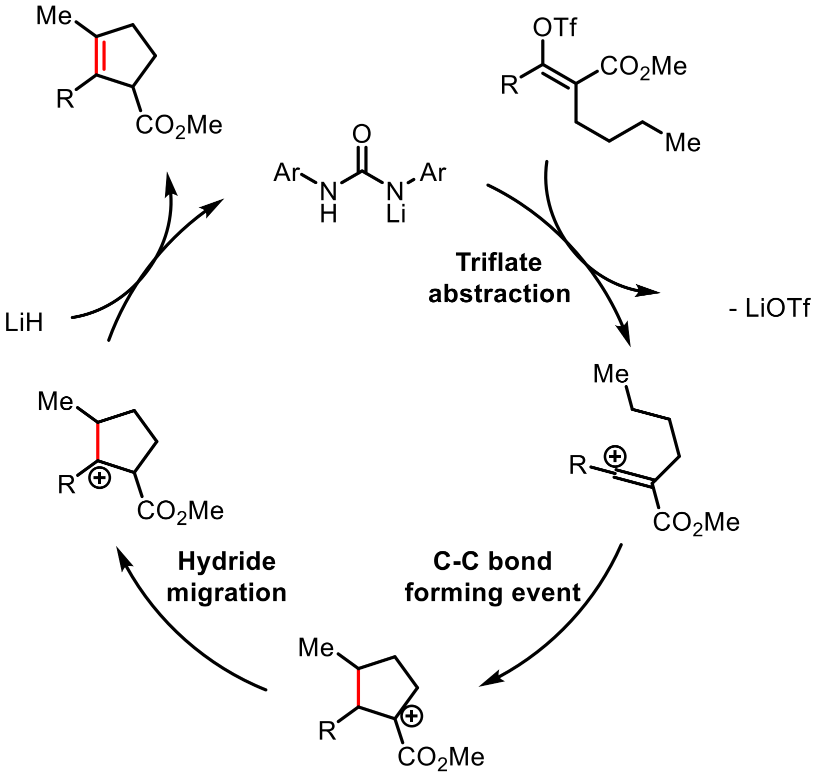
23% yield

B Attempted cyclopentene formation from propylated ester triflate



ND

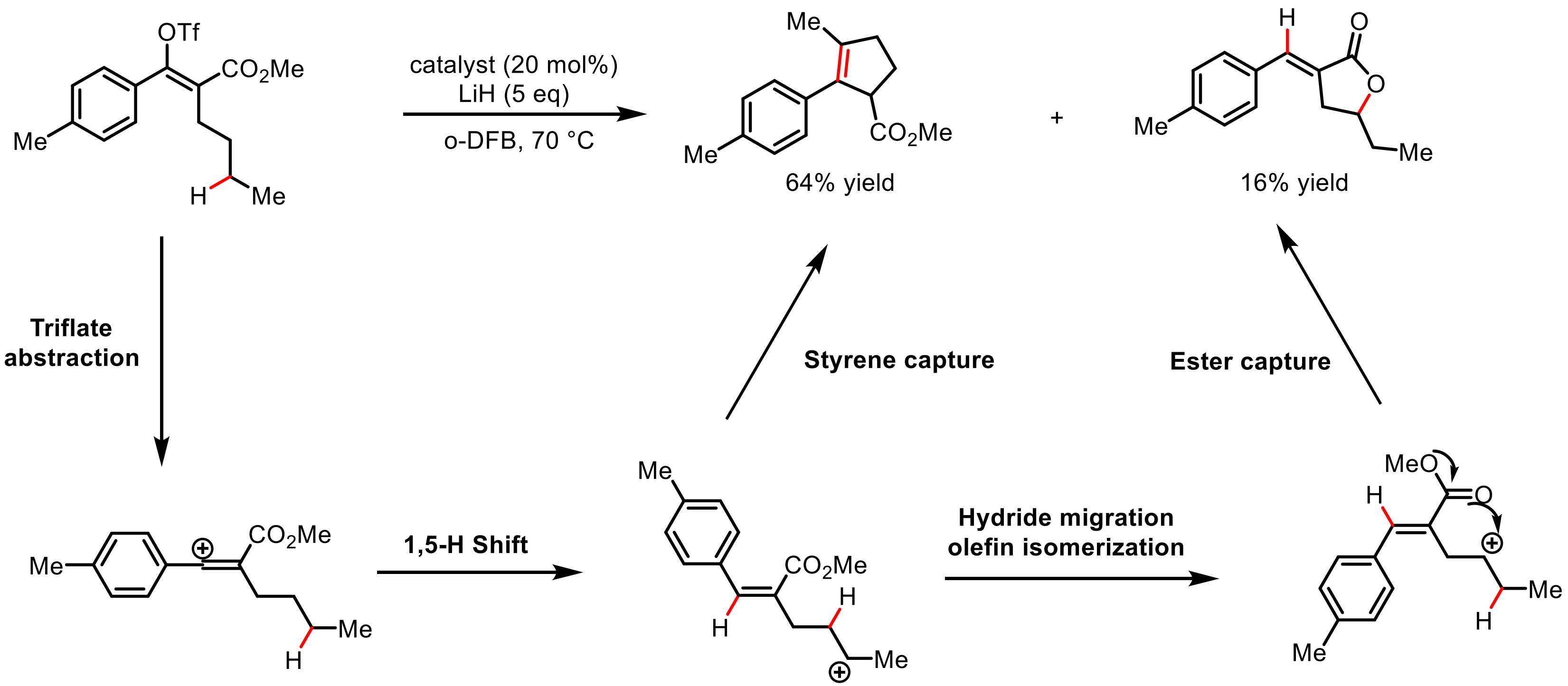
1° carbocation formation disfavored



H. M. Nelson, et. al. *Org. Lett.* **2020**, *22*, 7775−7779.

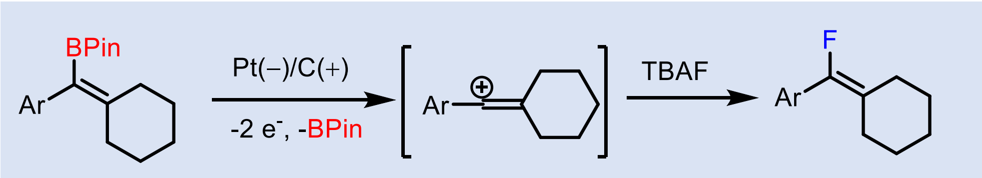
2.3 Vinyl Cations Produced in Situ by Vinyl Compounds

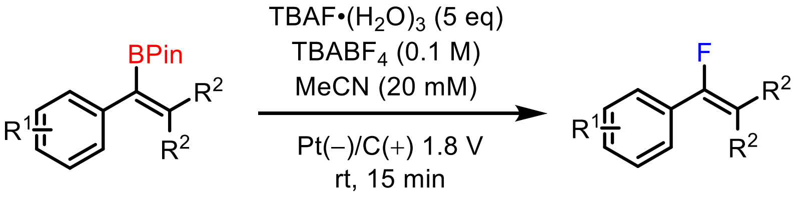
C Proposed pathway of the C-C bond forming evnt of vinylogous acyl triflates

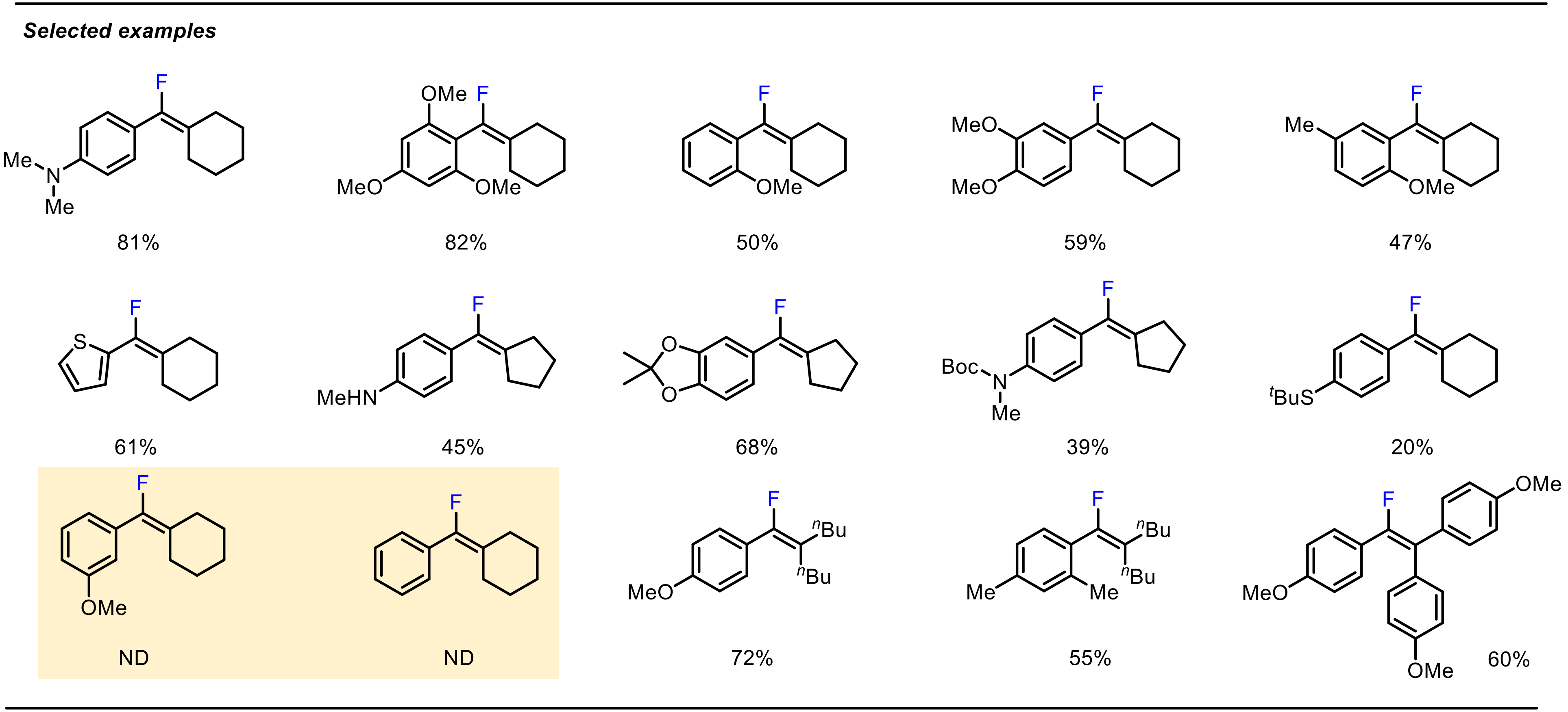


H. M. Nelson, et. al. *Org. Lett.* **2020**, *22*, 7775−7779.

2.3 Vinyl Cations Produced in Situ by Vinyl Compounds



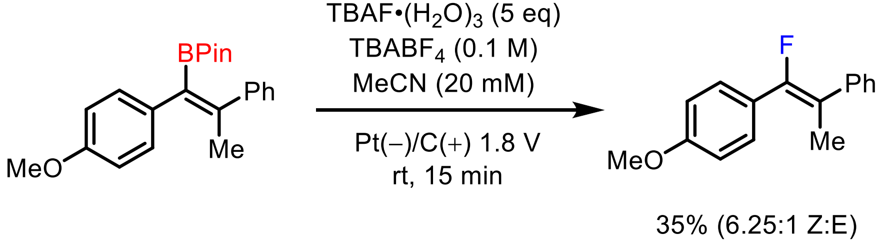




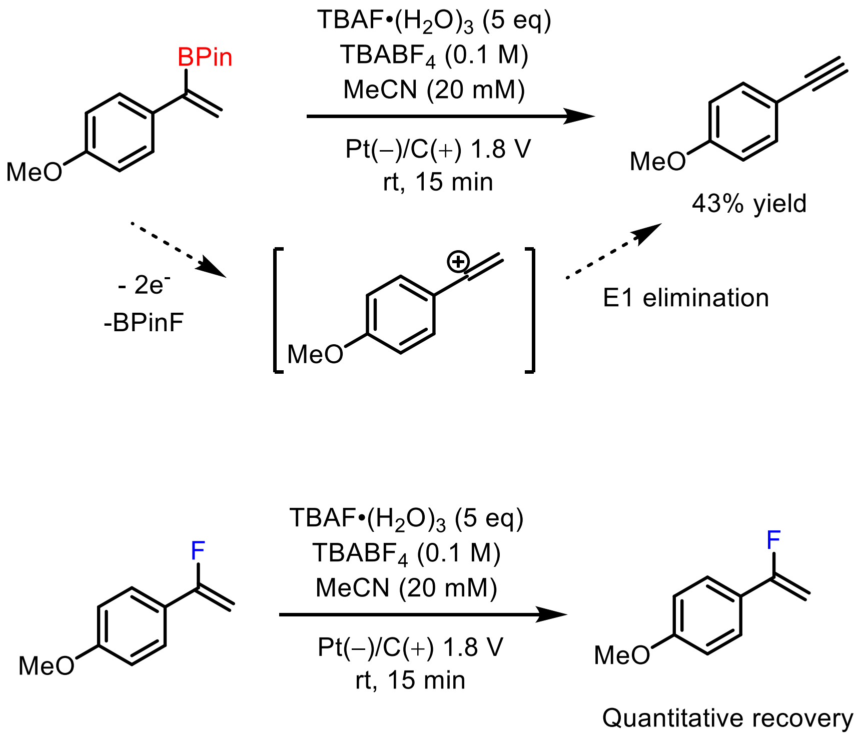
K. N. Houk, H. M. Nelson, et. al. *Angew. Chem. Int. Ed.* **2022**, *61*, e202113972.

2.3 Vinyl Cations Produced in Situ by Vinyl Compounds

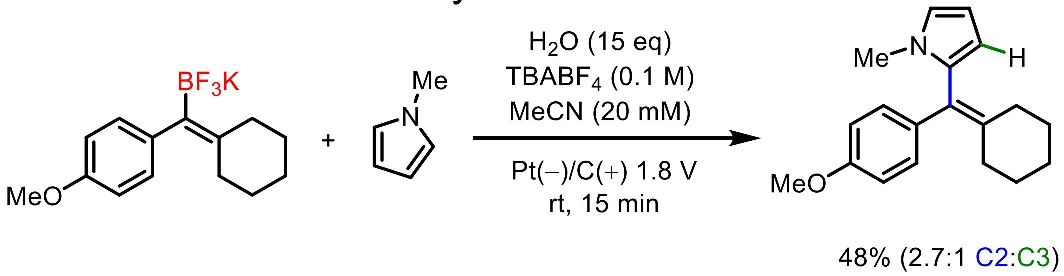
B Unsymmetric boronic ester reactivity



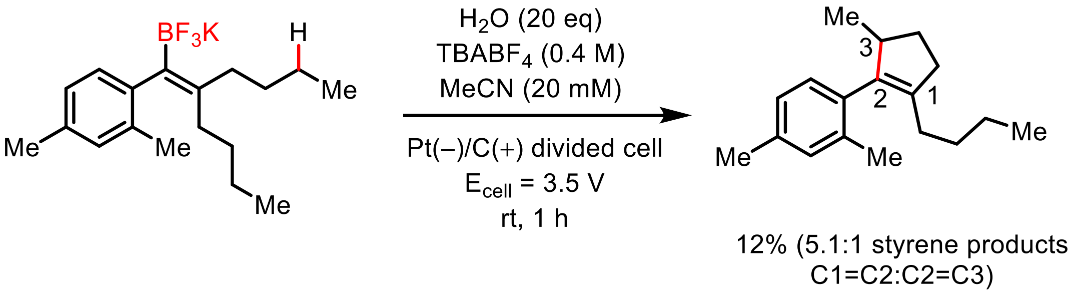
A Elimination reactivity



C Friedel-Crafts reacivity

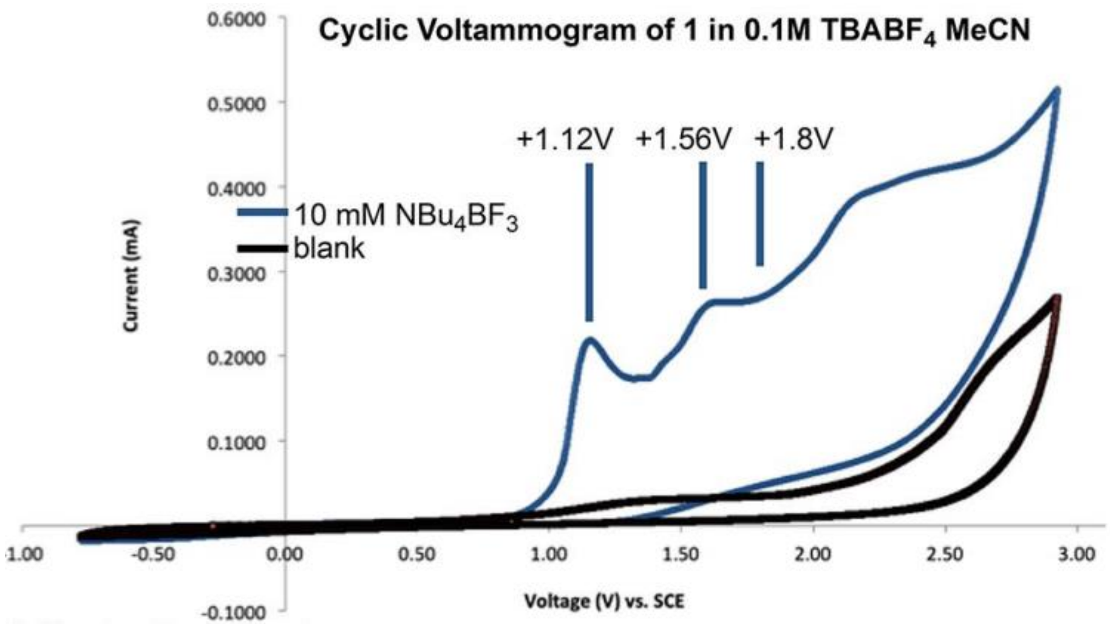


D C-H insertion reactivity



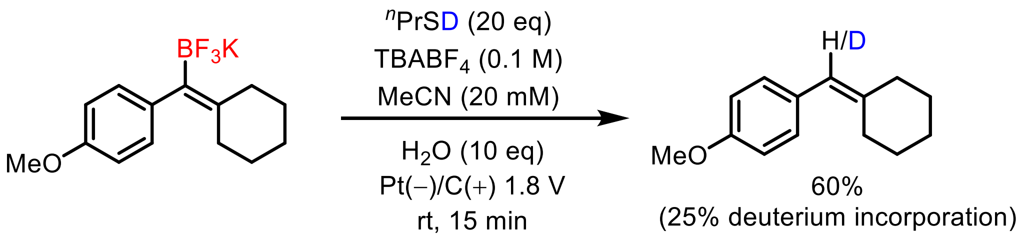
K. N. Houk, H. M. Nelson, et. al. *Angew. Chem. Int. Ed.* **2022**, *61*, e202113972.

2.3 Vinyl Cations Produced in Situ by Vinyl Compounds

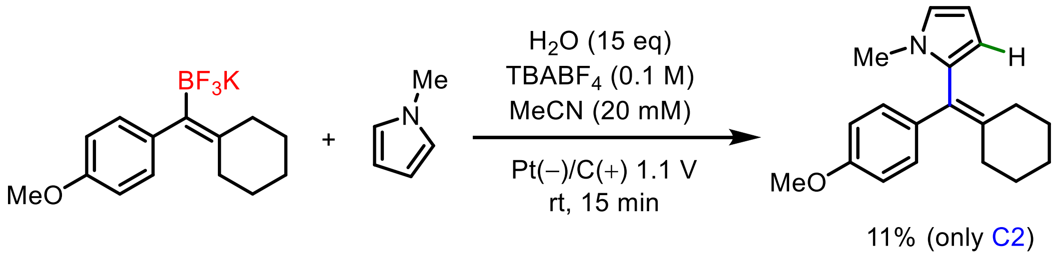


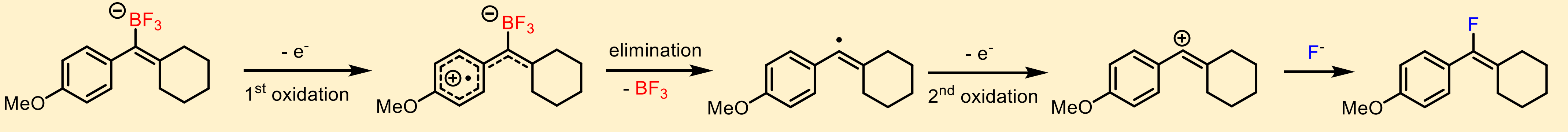
- 1.12 V: First oxidation potential
- 1.56 V: First oxidation potential
- 1.8 V: Standard potential

A Vinyl radical trapping



B Radical arylation reactivity at low potential

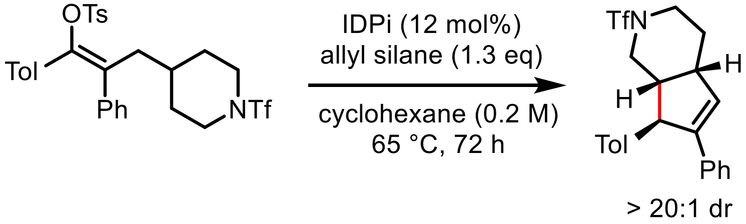




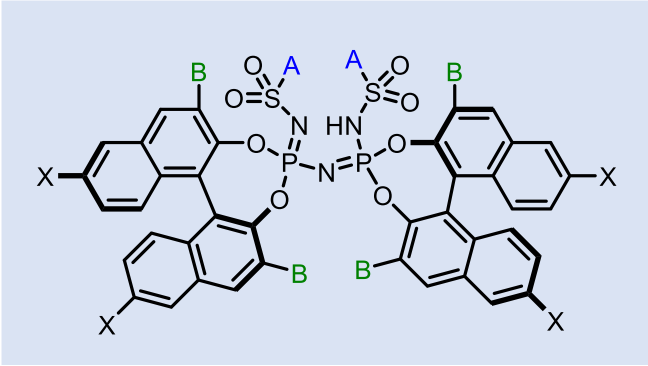
K. N. Houk, H. M. Nelson, et. al. *Angew. Chem. Int. Ed.* **2022**, *61*, e202113972.

2.3 Vinyl Cations Produced in Situ by Vinyl Compounds

The first enantioselective version of vinyl cations



Entry	IDPi	X	Silane	Yield	ee
1	A1B1	H	allyl TIPS	56%	52%
2	A1B2	CF_3	allyl TIPS	79%	85%
3	A1B3	CF_3	allyl TIPS	72%	60%
4	A1B4	CF_3	allyl TIPS	11%	84%
5	A1B5	CF_3	allyl TIPS	84%	85%
6	A1B6	CF_3	allyl TIPS	72%	91%
7	A1B6	CF_3	allyl TMS	34%	89%
8	A1B6	CF_3	allyl Si(TES)$_3$	91%	91%
9	A1B6	CF_3	none	0%	-



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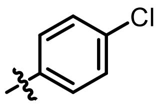
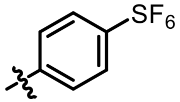
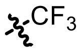


A2 =


B1 =


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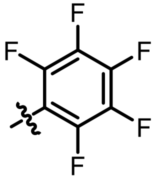

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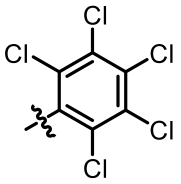
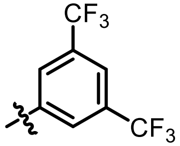
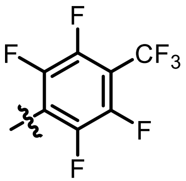
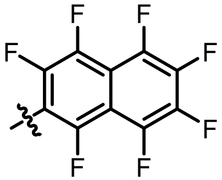


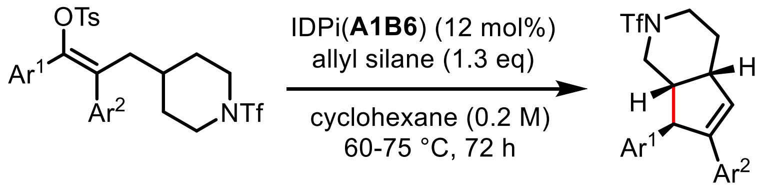
B4=


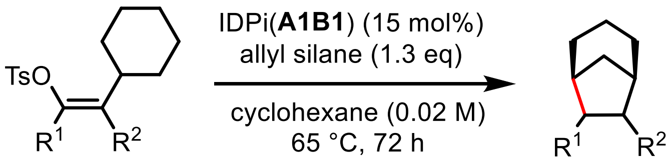
B5 =


B6 =


K. N. Houk, H. M. Nelson, et. al. *Science*, **2022**, *378*, 1085–1091.

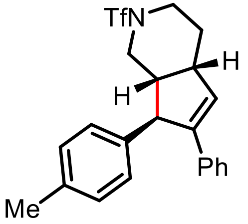
2.3 Vinyl Cations Produced in Situ by Vinyl Compounds



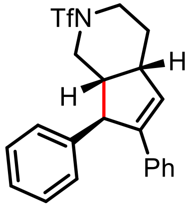


[3.2.1] bicycles
chiral if $R^1 \neq R^2$

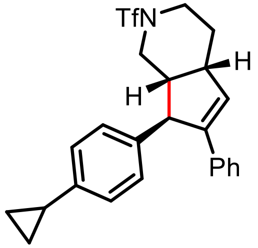
Selected examples



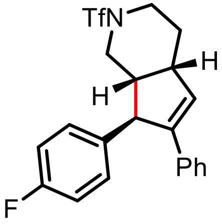
81% yield
> 20:1 dr
91% ee



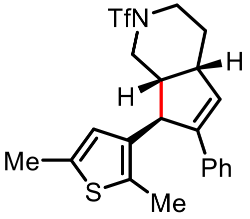
70% yield
> 20:1 dr
82% ee



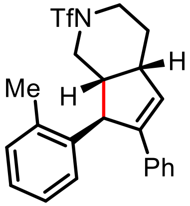
81% yield
> 20:1 dr
92% ee



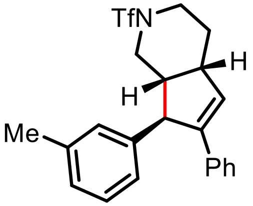
57% yield
> 20:1 dr
87% ee



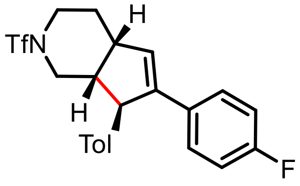
40% yield
> 20:1 dr
90% ee



89% yield
> 20:1 dr
88% ee

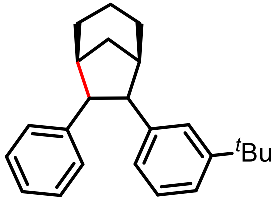


66% yield
> 20:1 dr
82% ee

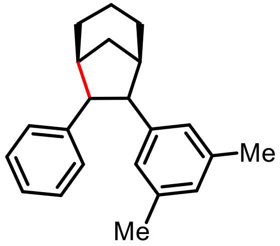


78% yield
> 20:1 dr
91% ee

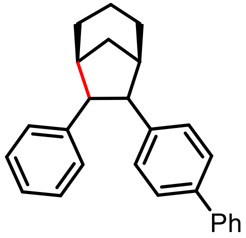
Selected examples



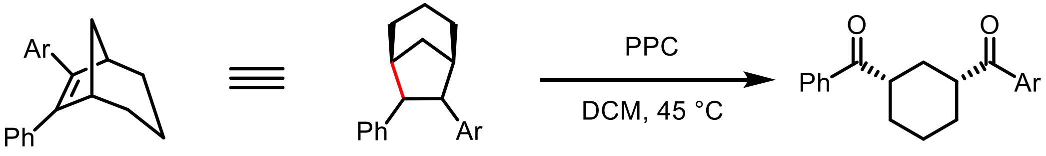
48% yield, 77% ee



46% yield, 73% ee



55% yield, 73% ee

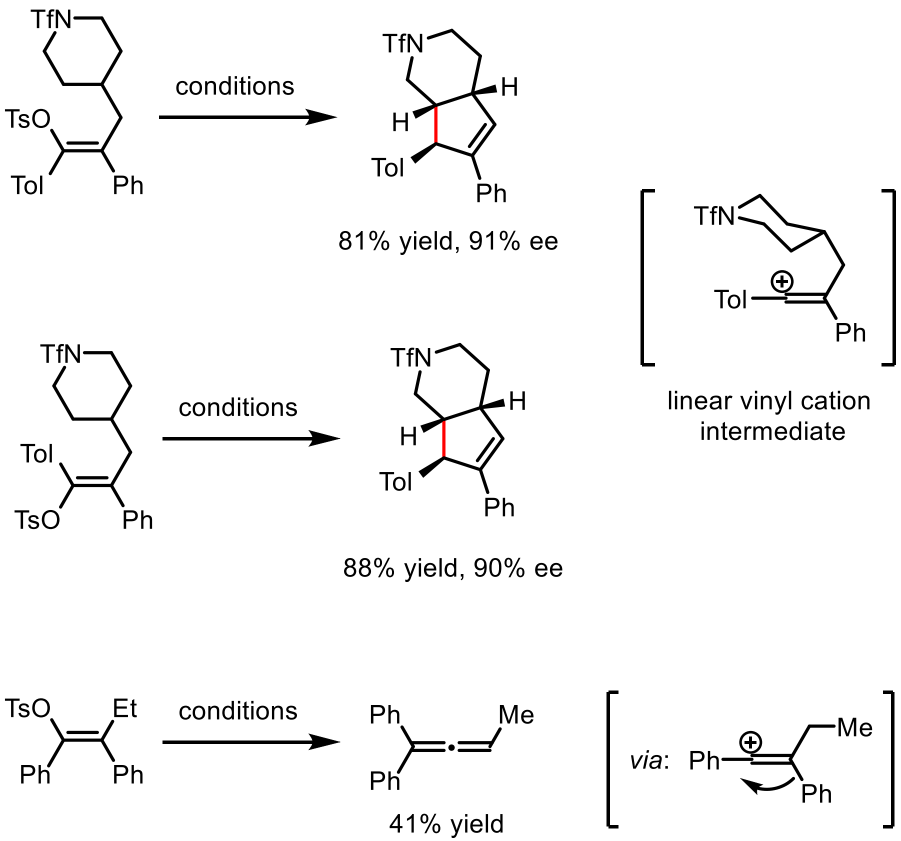


enantioenriched cyclohexanes
100% es

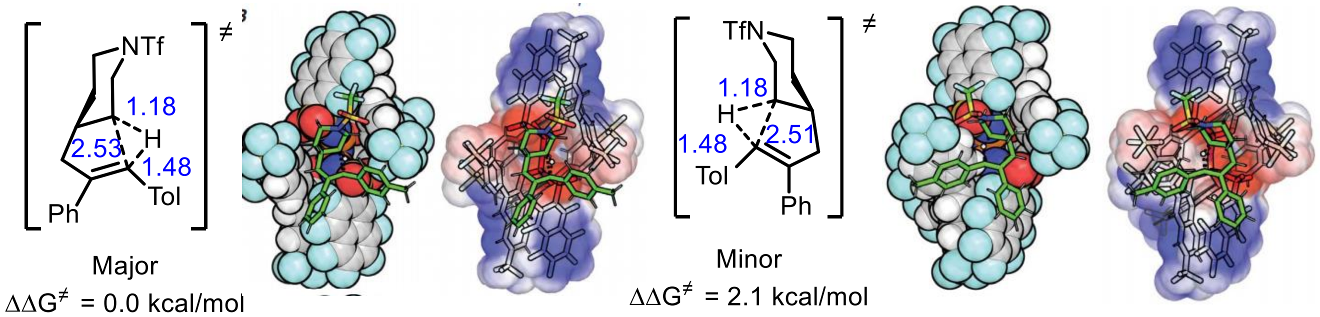
K. N. Houk, H. M. Nelson, et. al. *Science*, **2022**, *378*, 1085–1091.

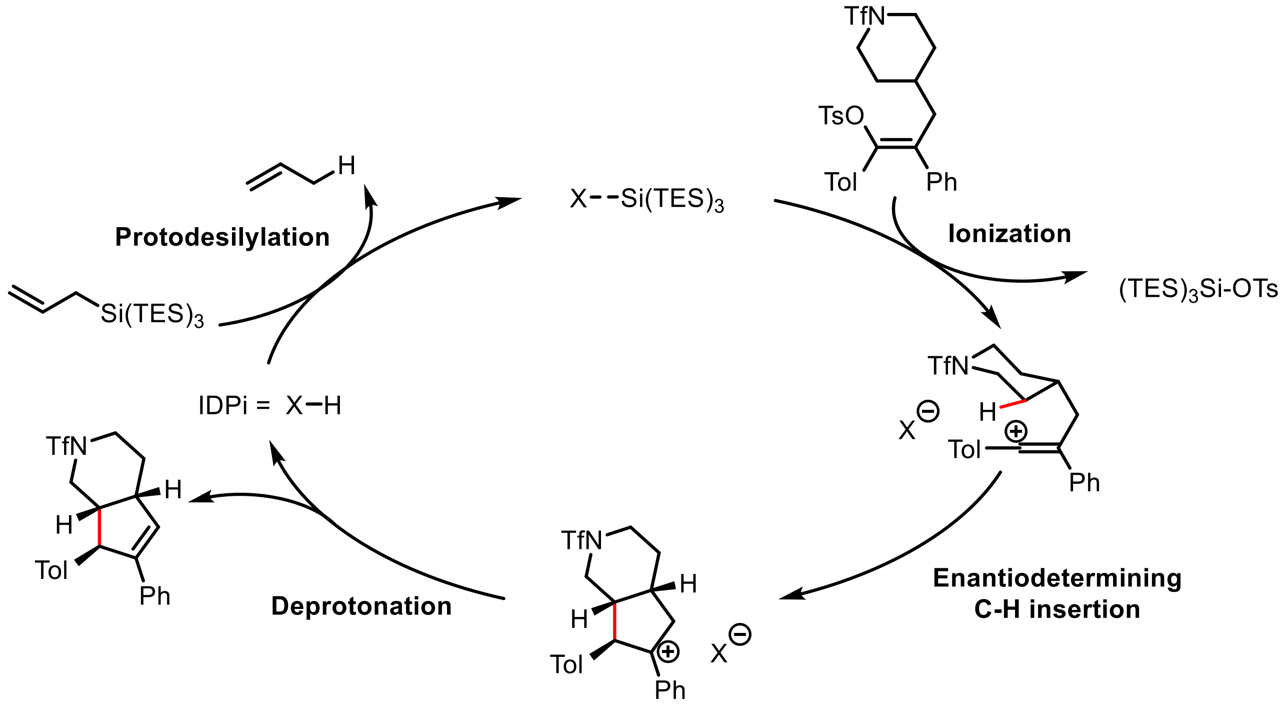
2.3 Vinyl Cations Produced in Situ by Vinyl Compounds

A Evidence of vinyl carbocation intermediacy



B DFT analysis of insertion TS



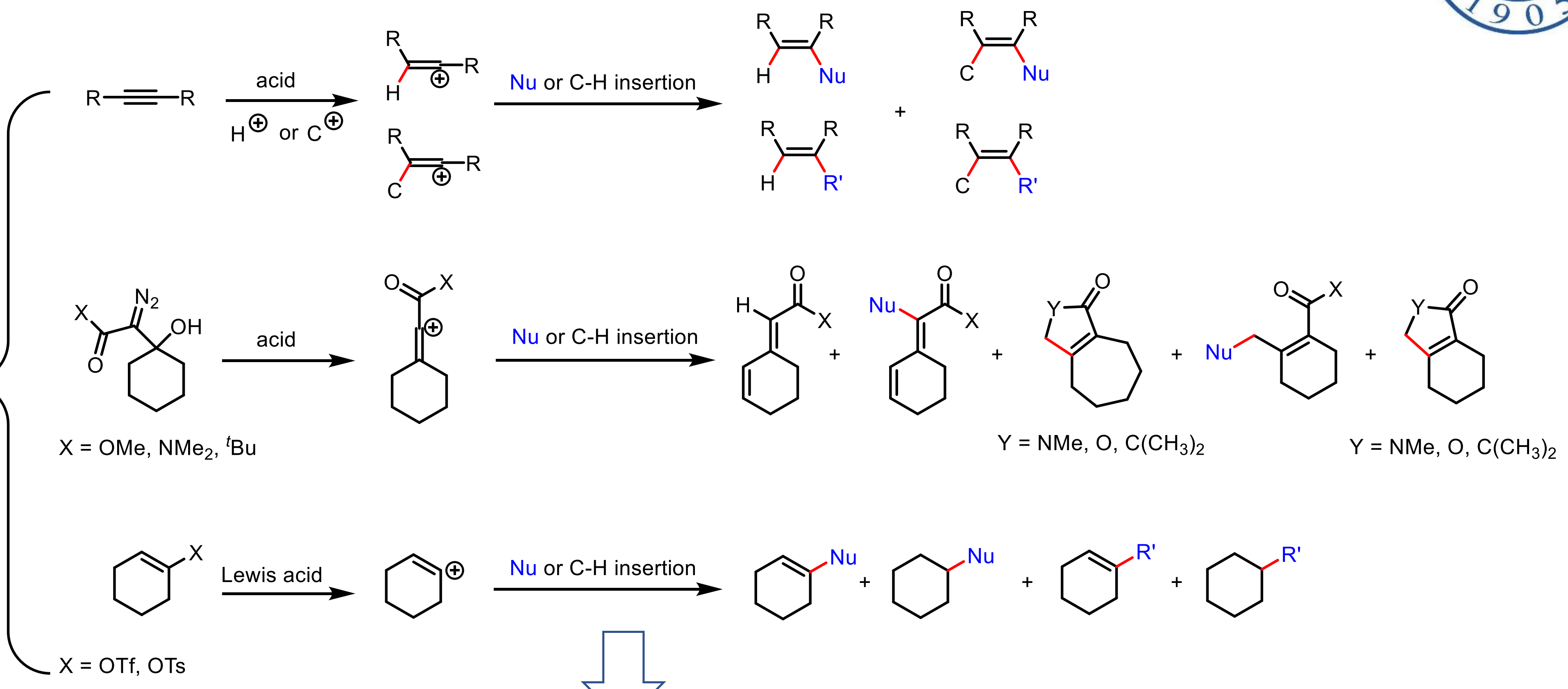


K. N. Houk, H. M. Nelson, et. al. *Science*, **2022**, *378*, 1085–1091.

Contents

3. Summary and Prospection

Methods of producing vinyl cations



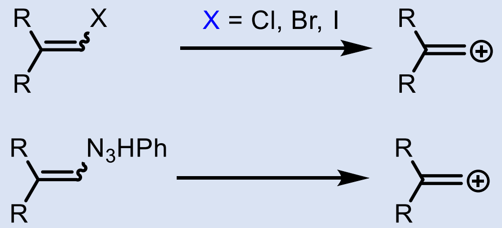
More new methods of producing vinyl cations

More reactivity of vinyl cations

The enantioselective version of vinyl cations are just booming!

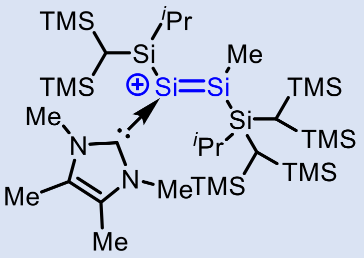
3. Summary and Prospection

More methods to get vinyl cation

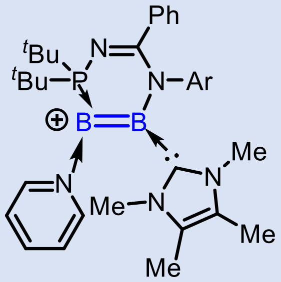


More stable structure of vinyl cation

Sekiguchi (2012)



Cheuk-Wai So (2022)



Use ligand to get the vinyl cation

More reactions of vinyl cation

Carbocation chemistry

Friedel−Crafts Alkylation

S_N1 and S_N1' Reactions

Wagner−Meerwein Rearrangements

Ritter Reaction

Schmidt Reaction

Pinacol and Prins-Pinacol Rearrangements

Nazarov Reaction

Vinyl cation
Nu or C-H insertion

A. Sekiguchi, et. al. *J. Am. Chem. Soc.* **2012**, *134*, 886–889.
C. W. So, et. al. *Angew. Chem. Int. Ed.* **2022**, *61*, e202212842.

Thanks For Your Attention