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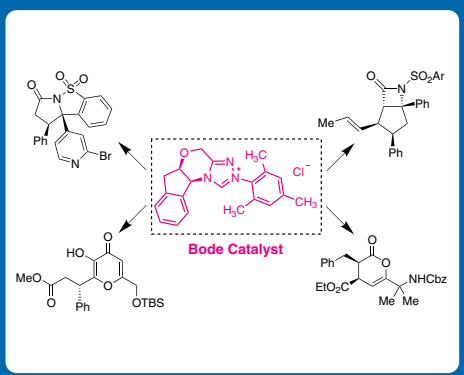

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寄稿論文

N-Mesityl Substituted Chiral Triazolium Salts: Opening a New World of N-Heterocyclic Carbene Catalysis

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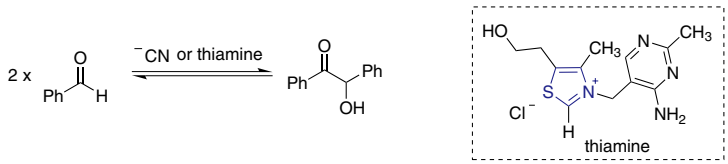
1 Introduction

The dimerization of aldehydes to form benzoins **(Scheme 1)** is one of the oldest known organic reactions, first reported in 1832 by Liebig.[1] The original cyanide catalyzed benzoin reaction was long appreciated for its simplicity and mechanistic intricacies but offered few useful synthetic applications.[2] The discovery by Ukai[3] in 1943 that the essential co-factor thiamine, or vitamin B1, catalyzes the benzoin reaction provided a key clue to understanding a broad range of thiamine-dependent enzymes and reinvigorate interest in this class of reactions.[4] The use of ylides derived from thiamine, which are now classified as N-heterocyclic carbenes,[5] led to both new reactions, such as the Stetter addition of aldehydes to electron-deficient olefins,[6] and new catalysts types inspired by the chemistry of the thiazolium salt at the heart of thiamine.[7] Key to the success of thiamine and its relative is the catalytic generation of an acyl anion equivalent.[8] Typical procedures for the preparation of this reactive species would require harsh conditions and intricate protecting group strategies. With thiamine catalysis, this reactive species can be generated under aqueous and nearly neutral conditions.

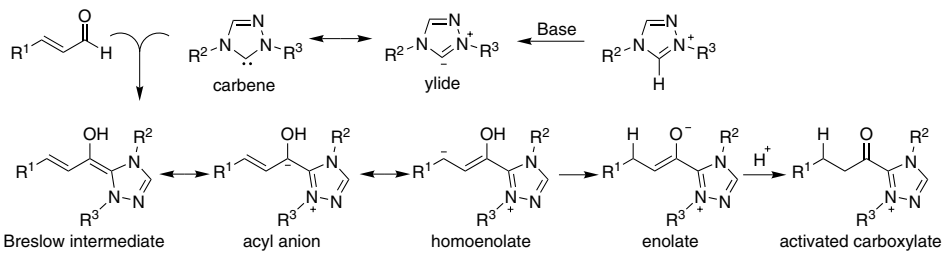


Scheme 1. Benzoin reaction with benzaldehydes.

By the year 2003, modern, enantioselective versions of the benzoin and certain Stetter reactions had emerged, driven by the design and preparation of new chiral azolium salts. Pioneering work by Knight and Leeper,[9] Enders,[10] and Rovis[11] had converged on the use of chiral, bicyclic triazolium salts as the ideal platform for N-heterocyclic carbene catalysts capable of inducing highly enantioselective reactions including intermolecular homo-benzoin reactions,[12] intramolecular Stetter reactions,[13] and intramolecular aldehyde–ketone crossed benzoin reactions.[14] These methods are now well established and widely employed for the enantioselective synthesis of complex molecules including bioactive natural products.[15]

2 NHC-Catalyzed Reactions of α-Functionalized Aldehydes

In late 2003, then at the University of California–Santa Barbara, we initiated a research program aimed at employing N-heterocyclic carbenes as catalysts for the formation of other reactive species. We recognized the combination of an N-heterocyclic carbene catalysts with an α-functionalized aldehyde, such as an α,β-unsaturated aldehyde or an α-halo aldehyde, could result in the generation of reactive species including homoenolate equivalents, enolate equivalents, and acyl azoliums, which serve as activated carboxylates **(Scheme 2)**.



Scheme 2. Reactive species generation from α,β-unsaturated aldehyde with N-heterocyclic carbene.

Within two years of our initial studies, we had developed catalysts and conditions that allowed for the selective formation of each of these reactive intermediates, making possible an entirely new class of catalytic reactions. Key to the success of this research program, and the vast number of new enantioselective transformations that it has enabled, was our recognition that *N*-mesityl substituted triazolium salts are critical for high reactivity and selectivity in N-heterocyclic carbene catalyzed reactions of α-functionalized aldehydes. Our initial studies, completed in 2005, identified achiral *N*-mesityl substituted catalyst **A** as the minimal structure required for the generation of these reactive intermediates under mild conditions.[16] In the following year, we disclosed chiral *N*-mesityl substituted triazolium salts **B** and ***ent*-B**.[17]

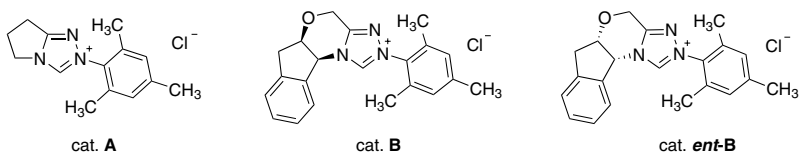
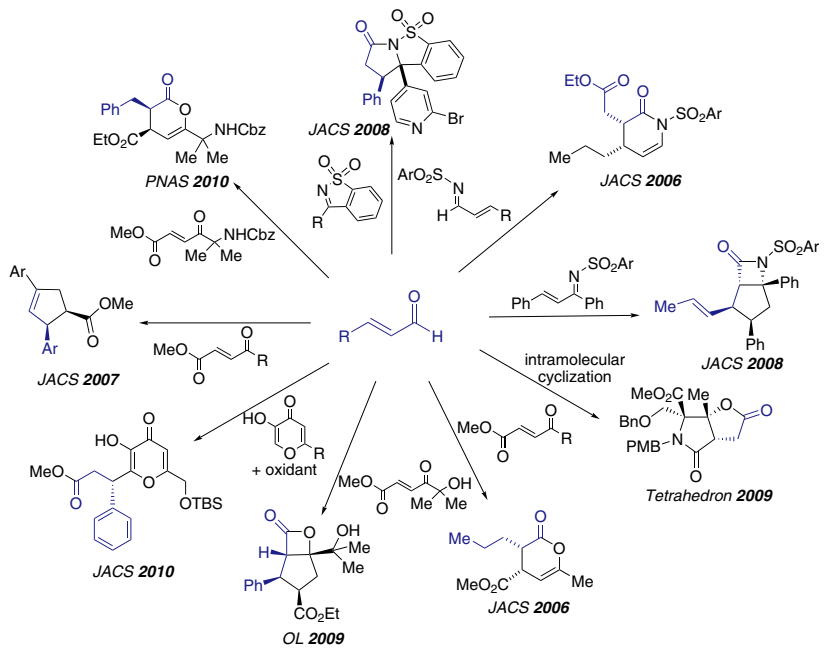


Chart 1. Achiral *N*-mesityl substituted catalyst **A**, chiral catalysts **B** and ***ent*-B**.

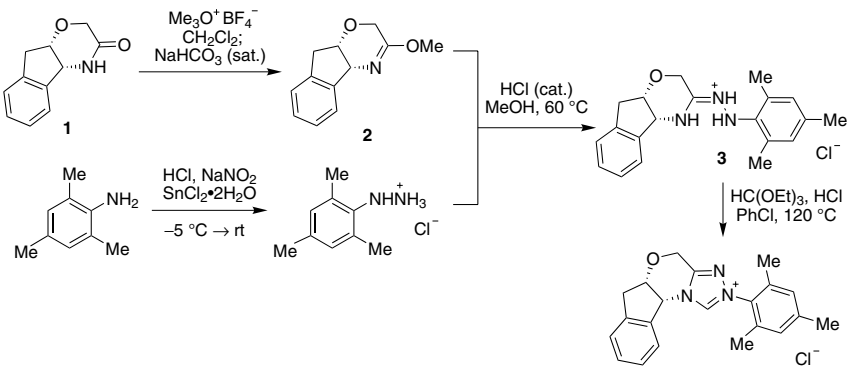
By developing an efficient synthetic route to incorporate the essential *N*-mesityl substitution, we are able to produce **B** on a preparative scale at modest cost. This catalyst promotes a large number of highly enantioselective transformations, otherwise not effected via other chiral azolium salts lacking an *N*-mesityl or related substitutent. These reactions and their scope are highlighted in the review below **(Scheme 3)**.



Scheme 3. Reactions promoted by chiral catalysts **B** and ***ent*-B**.

3 Catalyst Synthesis and Counterion Effects

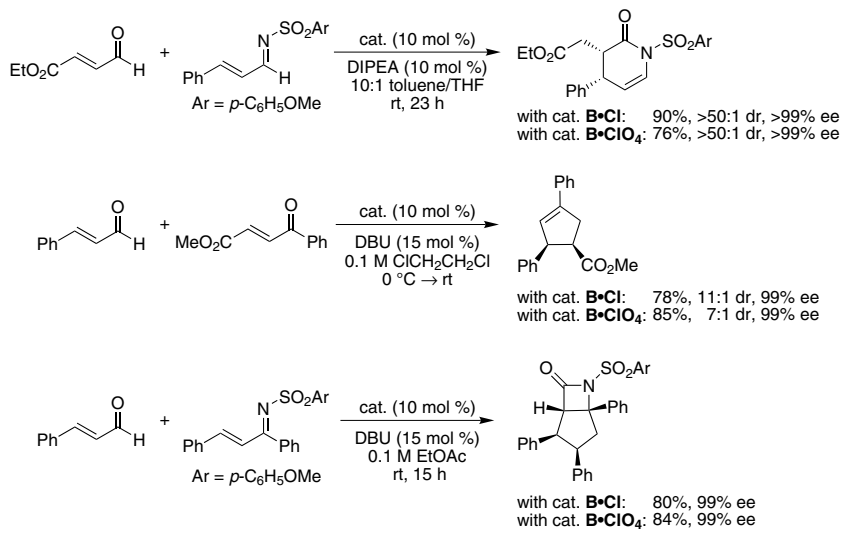
Our catalyst design borrows its chiral elements on the outstanding work of Knight and Leeper,[9] who first reported chiral triazolium salts derived from 1,2-amino alcohols, and of Rovis,[11] who first employed the readily available 1,2-aminoindanol for chiral azolium salts. In both cases, high quality *N*-mesityl-hydrazine hydrochloride is needed. While this is commercially available the cost is prohibitive for large scale syntheses. We have therefore devised a reliable procedure for the large scale preparation of this hydrazine salt from the corresponding aniline. Although yields are not high (36−40% yield), it can be execute on a 1 mol scale with inexpensive starting materials and without the need for chromatography or distillation.



Scheme 4. Synthesis of chiral triazolium catalyst ***ent*-B**.

The preparation of the chiral catalysts begins by following the work of Rovis, who has prepared aminoindanol derived triazoliums bearing different aromatic substituents.[13] Lactam **1** is converted to the imidate **2** with trimethyloxonium tetrafluoroborate and condensation with *N*-mesityl hydrazine affords **3 (Scheme 4)**. The most challenging step is the final ring closing, which fails or gives low yields under the previously developed conditions. Our modified procedures uses lower temperatures and HCl or $HClO_4$ to promote the ring closure. The resulting chloride or perchlorate salts are readily isolated and stored.[18]

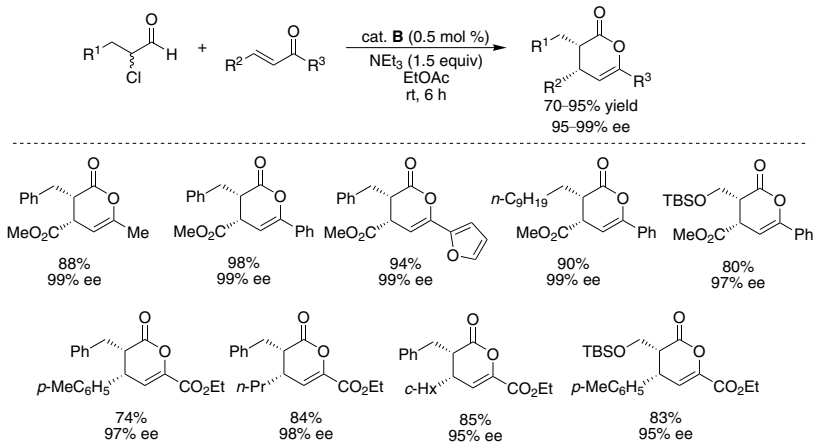
In all cases examined to date, the counterion plays no role in the reaction outcome. Thus catalysts of type **A** or **B** bearing chloride, perchlorate or tetrafluoroborate counterions give identical yields and enantioselectivities provided that at least a catalytic amount of base is used in the reactions **(Scheme 5)**.[19] The only discernable difference is that the chloride catalysts are somewhat more hydroscopic but this does not generally affect the reaction outcome.



Scheme 5. In the presence of bases, there is no significant effect of the azolium counterions. (DIPEA = *N,N*-diisopropylethylamine, DBU = 1,8-diazabiyclo-[5.4.0]undec-7-ene)

4 Hetero-Diels Alder Reactions

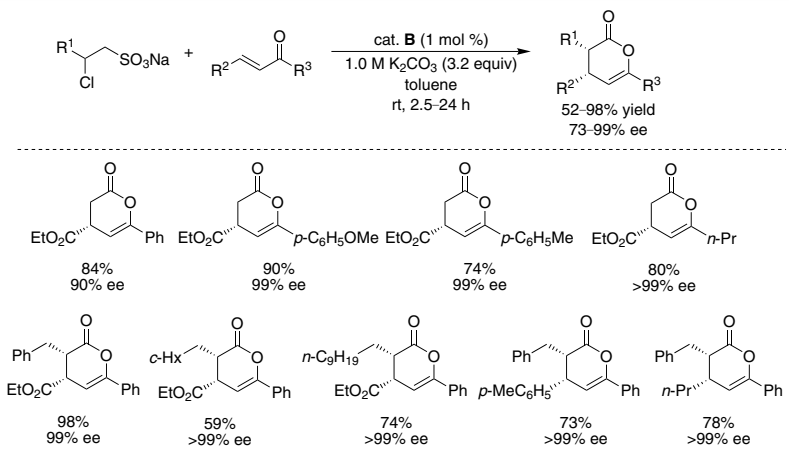
The catalytic generation of ester enolate equivalents under mild, simple conditions that allow for enantioselective reactions has been a long held goal of synthetic organic chemistry. In 2006, we disclosed the use of *N*-mesityl substituted triazolium salts for the catalytic generation of ester enolate equivalents from α-halo- and α,β-unsaturated aldehydes.



Scheme 6. Diels-Alder reactions of α-chloroaldehydes with oxodienes.

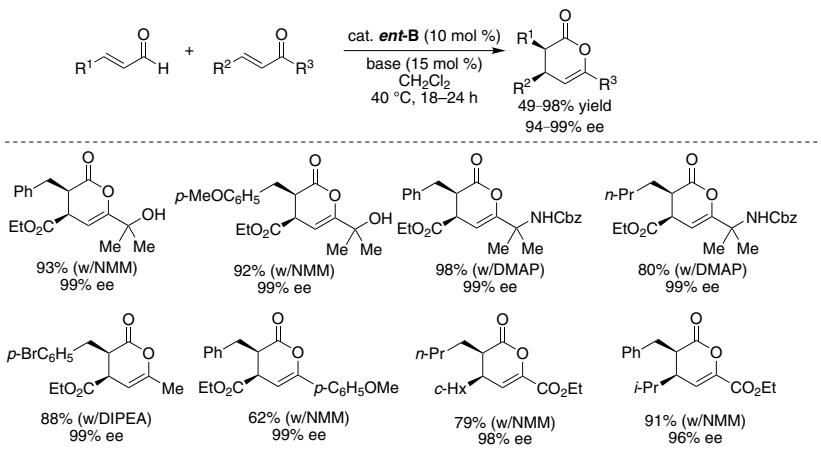
Racemic α-halo aldehydes undergo highly enantioselective annulations with electron deficient oxodienes under remarkably mild and simple reaction conditions **(Scheme 6)**.[20] Due to the high reactivity of these substrates, only 0.5 mol% of chiral triazolium salt **B** is needed for excellent yields and enantio-selectivities. The racemic α-halo aldehydes undergo epimerization in the reaction conditions rending this reaction an enantio-convergent process. The scope of this process is outstanding, with either aromatic or aliphatic substuents tolerated by both reaction partners.

The α-halo aldehyde starting materials are readily prepared in a single step from the corresponding aldehydes. They have, however, limited shelf life. We have therefore developed conditions for isolating and storing them as their bisulfite adducts and developed biphasic reaction conditions for the use of these convenient starting materials directly in the enantioselective annulation reactions **(Scheme 7)**.[21] Similarly high yields, enantioselectivities, and substrate scope are observed even under aqueous conditions. Importantly, this procedure works well with the commercially available bisulfite adduct of chloroacetaldehyde, making possible enantioselective acetate additions without the need to prepare the toxic and potentially explosive α-chloroaldehyde.



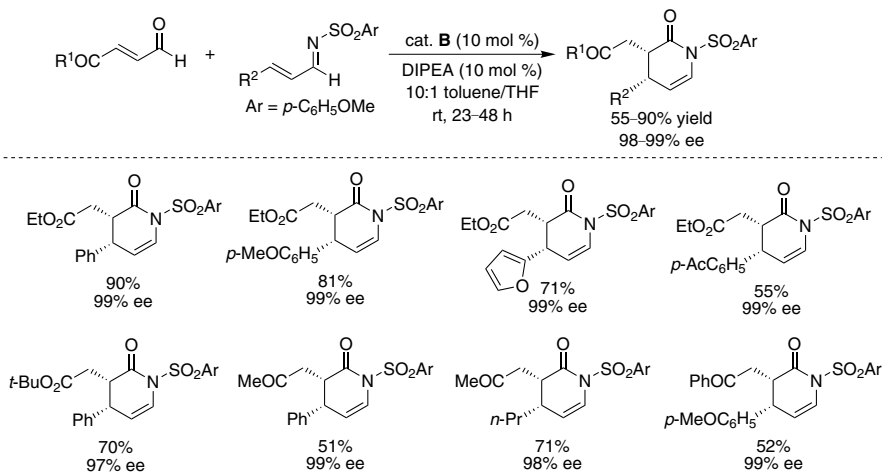
Scheme 7. Diels-Alder reactions with α-chloroaldehyde bisulfite salts.

The identical reactive intermediates can be generated from α,β-unsaturated aldehydes and we have recently reported a method for highly enantioselective annulations from both aromatic and aliphatic substituted enals **(Scheme 8)**.[22] Under these conditions, high catalysts loadings are needed due to the fact that only a trace amount of the active carbene catalysts is generated by the weak bases. This procedure also expands the scope of the annulations to include α-hydroxy- and α-aminoenones that give products bearing valuable synthetic handles for further transformations. Scheidt has also applied these chiral catalysts to an intra-molecular variant of this reaction.[23]



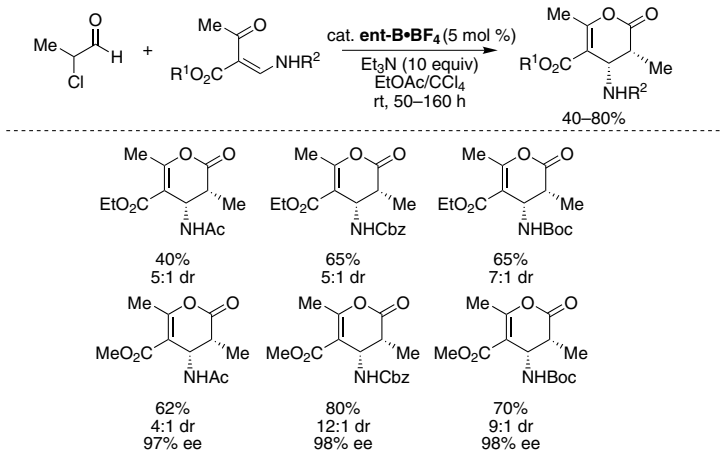
Scheme 8. Diels-Alder reactions with α,β-unsaturated aldehydes. (NMM = *N*-methylmorpholine, DMAP = 4-(dimethylamino)pyridine)

The heterodiene can also be extended to nitrogen analogues using either α-chloroaldehydes or commercially available electron-deficient enals as the enolate precursors **(Scheme 9)**.[17] This procedure affords *cis*-disubstituted dihydropyridinones in good yields and with outstanding enantioselectivities.



Scheme 9. Azadiene Diels-Alder reactions using α,β-unsaturated aldehydes.

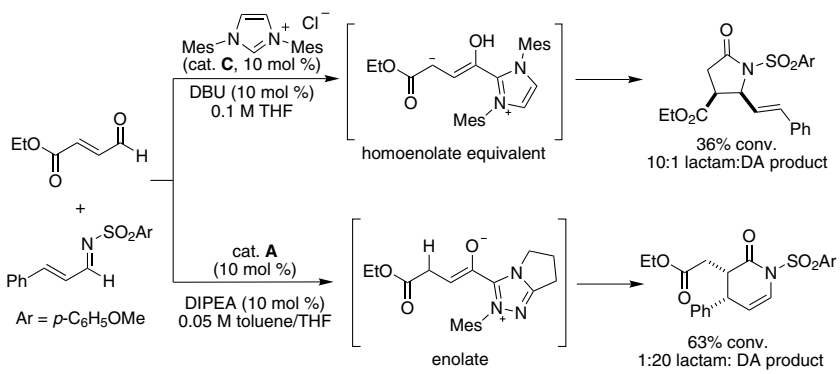
Recently, several other groups have used our catalyst and conditions for even more complex hetero-Diels-Alder reactions. An excellent example is that of Kobayashi and coworkers, who reported the formation of amine-substituted products by reactions of α-haloaldehydes and vinylogous amides **(Scheme 10)**.[24]



Scheme 10. Azadiene Diels-Alder reactions using α,β-unsaturated aldehydes.

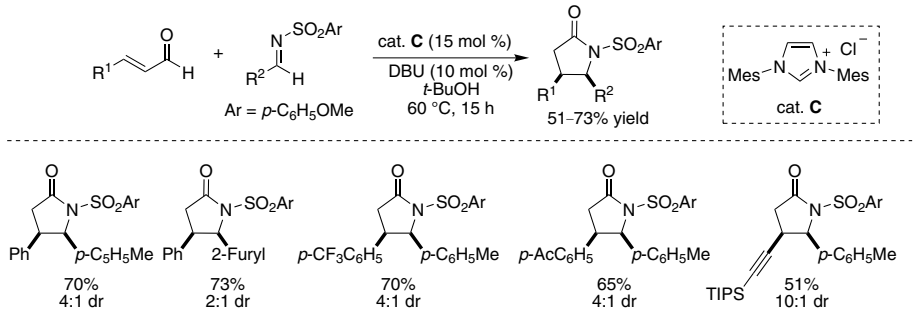
5 Catalytic Generation of Homoenolate Equivalents

The nature of the azolium catalyst employed in the annulation reactions plays an important role in the type of reactive intermediate generated. α,β-Unsaturated aldehydes can access either the homoenolate or enolate pathways. In general, the enolate pathway is favored by the use of weak bases (DMAP or NMM) and triazolium catalysts, while stronger bases (DBU) and imidazolium-derived N-heterocyclic carbenes prefer the homoenolate equivalent route. Reactions that proceed via the homoenolate pathway generate five-membered ring products such as γ-lactams, γ-lactones, or cyclopentane derivatives. For example, the same substrates shown in **Scheme 11** give either γ-lactams or dihydropyridinones depending on the catalyst type.[17]



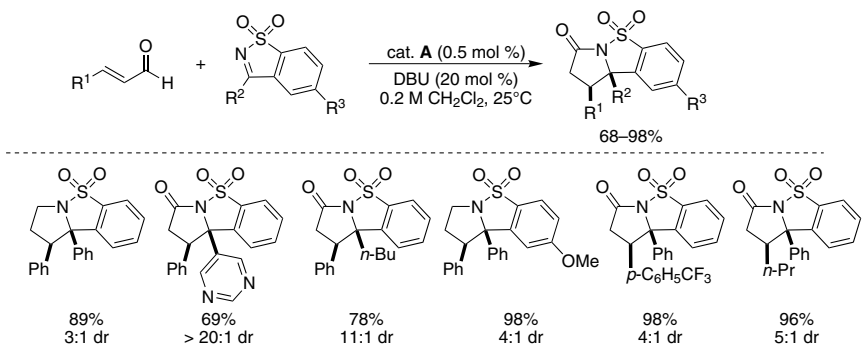
Scheme 11. Catalyst effects with α,β-unsaturated aldehydes and imines.

In general, imidazolium-derived catalysts are superior to triazolium-derived variants for γ-lactone[25] and γ-lactam[26] formation, with commercially available IMesCl (cat. **C**, CAS Nr. 141556-45-8) as the best achiral catalysts for many of these transformations **(Scheme 12)**.



Scheme 12. γ-Lactam formation promoted by IMesCl (cat. **C**).

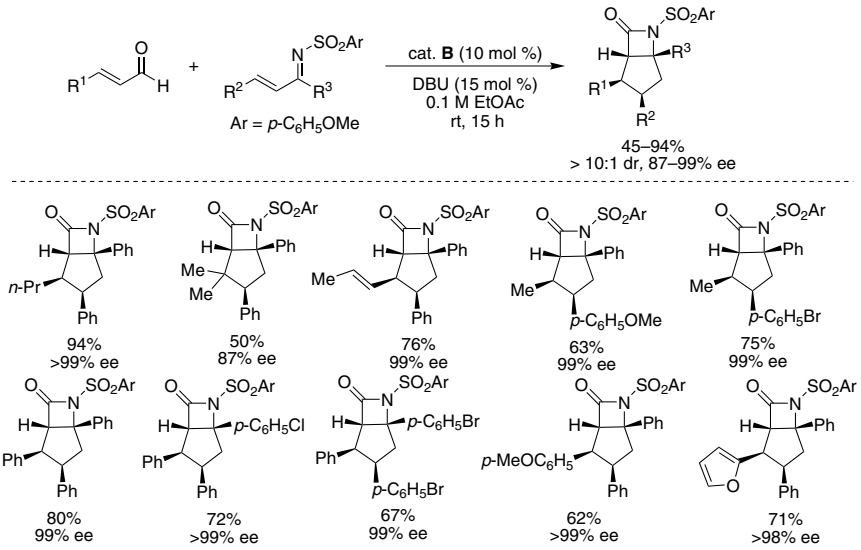
For certain highly reactive electrophiles, *N*-mesityl substituted triazolium salts are also active. The actual reaction mechanisms may be more complex in these cases, but the products are those derived from formal homoenolate generation and addition. Several such examples are listed below.



Scheme 13. Homoenolate additions of saccharine derived-cyclic ketimines.

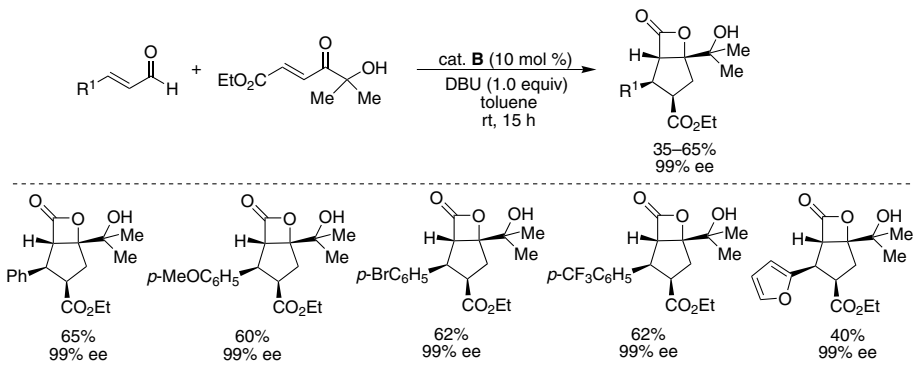
Saccharine derived-cyclic ketimines are unexpectedly good electrophiles in NHC-catalyzed annulations with enals using achiral triazolium salt **A (Scheme 13)**.[27] These reactions demonstrate broad scope in both the enal and ketimine reaction partner and afford unique polycyclic products in excellent yield and with low catalysts loading. Although chiral triazolium salt **B** is also an excellent catalyst for this reaction, enantioselectivities are relatively modest. This reflects the known difficulty of effecting highly enantioselective reactions that proceed via the homoenolate pathway.

When α,β-unsaturated *N*-tosyl ketimines are used as substrates, bicyclic β-lactams, rather than γ-lactams are formed **(Scheme 14)**.[28] This reaction is most easily thought of as a conjugate addition of the homoenolate derived from the α,β-unsaturated aldehyde followed by ring-closing reactions, although the actual reaction mechanism probably involves a different pathway. This remarkable cascade process affords enantiopure β-lactams in excellent yields and stereoselectivities.



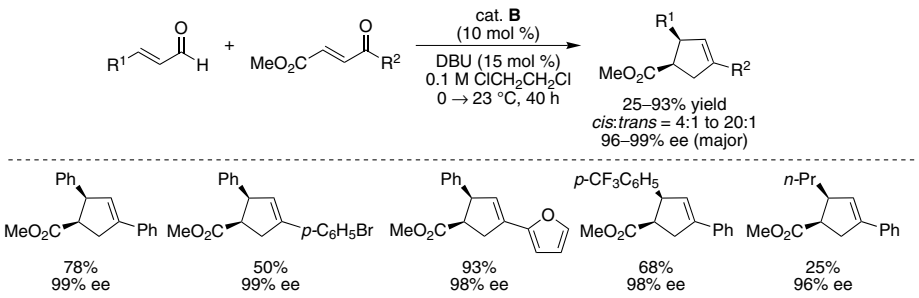
Scheme 14. Bicyclo-β-lactam annulations.

A similar reaction for the formation of enantiopure cyclopentyl β-lactones is also possible with the same catalyst and unsaturated aldehydes **(Scheme 15)**.[29] In this case, the use of α'-hydroxyenones is essential and provides a useful synthetic handle for the elaboration of the products.



Scheme 15. Enantiopure bicyclo-β-lactone annulations.

With enones bearing an aromatic group, the initial β-lactone products undergo spontaneous decarboxylation to afford disubstituted-cyclopentenes **(Scheme 16)**. The overall reaction allows the combination of an enal and a simple enone to give enantioenriched cyclopentenes in a single step and under mild, simple reaction conditions.[30]

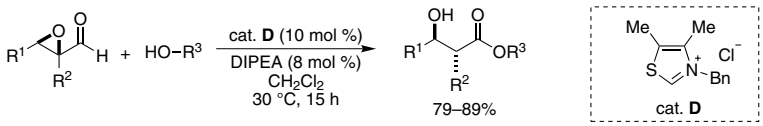


Scheme 16. Enantiopure bicyclo-β-lactone annulations.

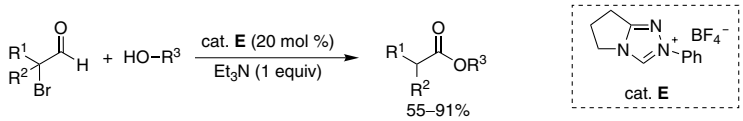
6 Catalytic Generation of Activated Carboxylates

In all of the reactions noted above, catalyst turnover is affected by the formation of an acyl azolium species that undergoes a lactonization or lactamization reaction. These acyl azolium intermediates therefore serve as catalytically generated activated carboxylates and can be used for esterification and amidation reactions. By choosing the appropriate substrates, N-heterocyclic carbene catalysts can effect both esterifications and amidations under catalytic conditions that do not require coupling reagents or produce chemical waste.

The first reports on the catalytic generation of acyl azoliums for esterification reactions utilized simpler azolium salts. In 2004, our group reported the diastereoselective opening of α,β-epoxyaldehydes with simple thiazolium-derived ylides **(Scheme 17)**.[31] The *N*-mesityl substituted triazolium salt **A** also catalyzes this reaction and is in many cases the superior reagent. Rovis, also in 2004, reported the generation of acyl azoliums from α-halo aldehydes using *N*-phenyl substituted triazolium salt **E (Scheme 18)**.[32] Rovis has also described an impressive example of enantioselective protonation using a chiral *N*-pentafluorophenyl substituted triazolium salt.[33]

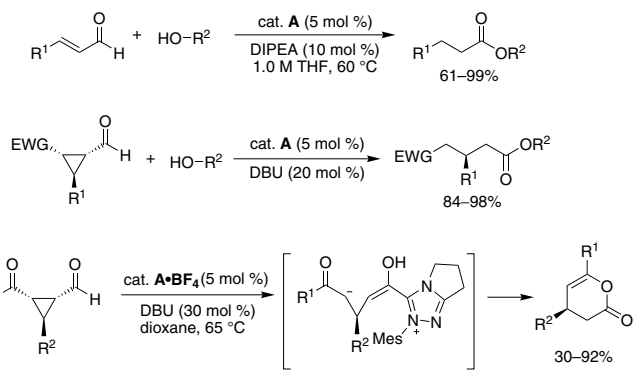


Scheme 17. Formation of esters from α,β-epoxyaldehydes.



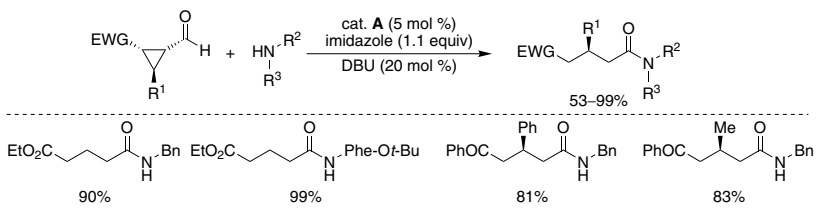
Scheme 18. Formation of esters from α-bromoaldehydes.

Although a number of azolium precatalysts can be used for redox esterification reactions of α-functionalized aldehydes, the *N*-mesityl or *N*-pentafluorophenyl substituted triazolium salts usually give superior results. A rapidly growing body of literature on these reactions has established that almost any aldehyde with an α-leaving group or reversible functionality serves as a substrate for NHC-catalyzed redox esterifications. The *N*-mesityl substituted catalyst is particularly suited for redox reaction of α,β-unsaturated aldehydes **(Scheme 19)**.[16] Other applications include the opening of enantioenriched formyl cyclopropanes to generate esters[34] or dihydropyranones reported by You and coworkers.[35]



Scheme 19. Redox reactions promoted by catalyst **A**

A curious finding of both our group and several others is the reluctance of catalytically generated acyl azoliums to undergo reactions with amines to form amides. This property can be exploited for the chemoselective acylation of alcohols in the presence of amines. The origin of this unusual reactivity lies in the unique properties of the acyl azoliums themselves, which do not readily react with amines to form amide products.[36] Successful NHC-catalyzed amidations do occur with the addition of suitable co-catalysts. In our hands, we have found that the addition of imidazole or similar triazoles make catalytic amidations of α-functionalized aldehydes possible, via the intermediacy of an acyl imidazole that reacts with the amine **(Scheme 20)**.[37] Similar chemistry using HOAt as the co-catalytic acylating agent was reported simultaneously by Rovis.[38]

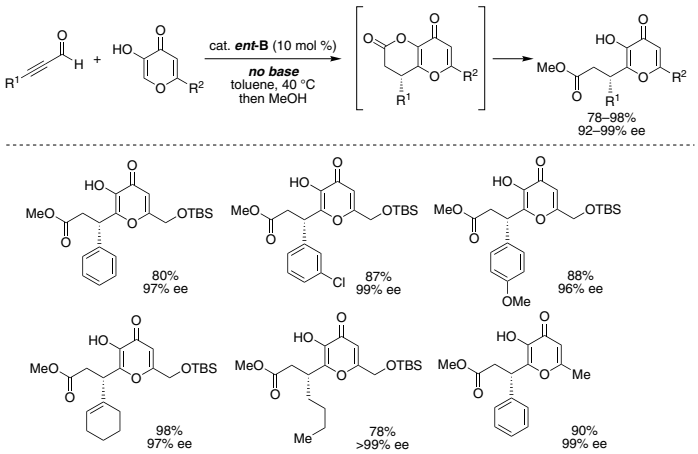


Scheme 20. Redox amidations.

7 Catalytic Annulations by NHC-Catalyzed Claisen Rearrangements

The combination of a chiral N-heterocyclic carbene catalysts and an ynals should lead to the formation of an α,β-unsaturated acyl azolium that may act as an electrophile, representing a completely different activation mode

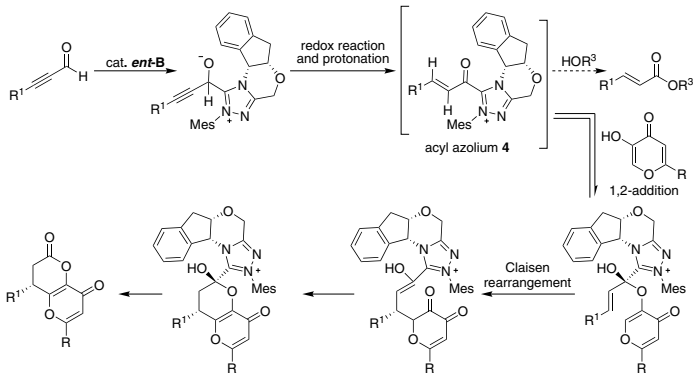
than the acyl anion, homoenolate, ester enolate, or activated carboxylate equivalents discussed so far. Using the identical chiral catalyst, we succeeded in identifying conditions for the selective generation of such intermediates and their use in annulation reactions with enolic substrates, such as kojic acid derivatives **(Scheme 21)**.[39]



Scheme 21. Enantioselective annulations of ynals and kojic acids.

Our initial work focused on kojic acids as substrates due to their known synthetic utility, but similar conditions give annulation products from pyruvates in excellent yields and selectivities. Recently reported chemistry from other groups using 1,3-dicarbonyls as nucleophiles are likely to proceed via a similar mechanism and should be amenable to enantioselective catalysis with chiral catalyst **B** or its relatives.[40] The reactions may also be conducted by starting from the α,β-unsaturated aldehyde and a stoichiometric oxidant with no effect to the observed enantioselectivities.[39]

The mechanism of this reaction is also of considerable interest. Although we initially believed the α,β-unsaturated acyl azolium **4** would be an excellent Michael acceptor, we have been unsuccessful in adding any nucleophiles other than enolates or MeOH/water. This led us to extensively investigate the detailed mechanism revealing an NHC-catalyzed Coates-Claisen rearrangement as the key step. This mechanistic postulate rationalizes the exceptional enantioselectivities observed in this reaction **(Scheme 22)**.



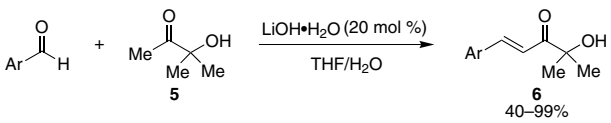
Scheme 22. Mechanism of Claisen rearrangements.

8 α'-Hydroxyenones as Enal Surrogates

The majority of the reaction described in this review use α,β-unsaturated aldehydes as starting materials. Although not obscure compounds, the vast majority of substrates require multiple steps for their preparation. This is particularly true of the highly desired heteroaromatic substrates for which the methods of enal synthesis are complicated by the presence of basic functionality.

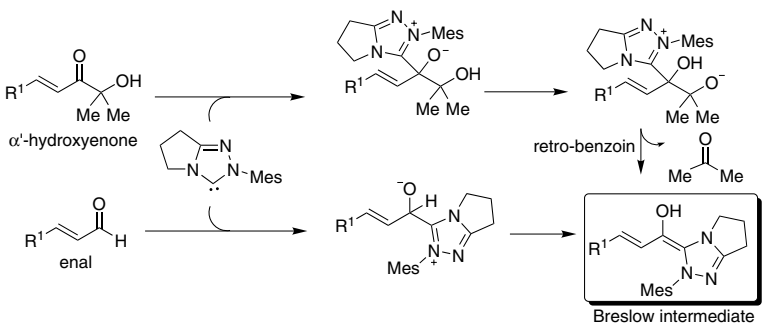
In order to improve the scope of the NHC-catalyzed reactions and expand the range of products that may be prepared with these methods, we have sought readily prepared, bench stable surrogates for aldehydes reaction partners. For ester enolate equivalents, the α-chloroaldehyde bisulfite adducts are ideal,[21] but these cannot be used for reactions involving homoenolate equivalents.

We have therefore developed α'-hydroxyenones **6** as readily prepared surrogates for α,β-unsaturated aldehydes.[41] These substrates can be prepared on a multigram scale from commercially available ketone **5** and aromatic aldehydes **(Scheme 23).**



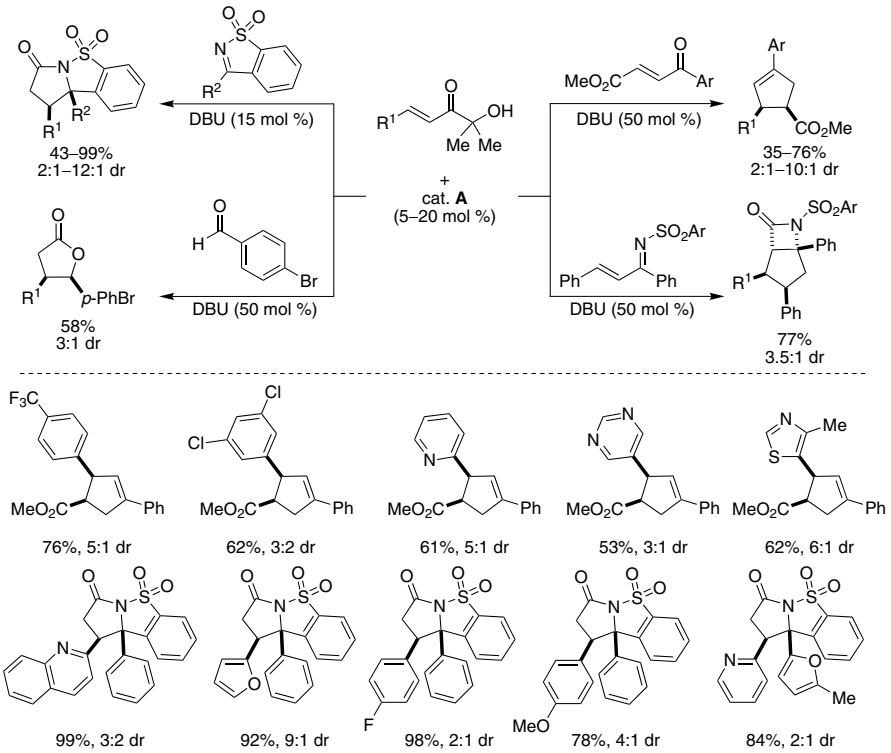
Scheme 23. Base catalyzed aldol reactions of α'-hydroxyenones synthesis.

In the presence of an N-heterocyclic carbene, the α'-hydroxyenones undergo identical reactions as the corresponding α,β-unsaturated aldehydes. In this case, the key reactive intermediates are formed by a retro-benzoin reaction of the initial NHC-ketone adduct **(Scheme 24)**.[42]



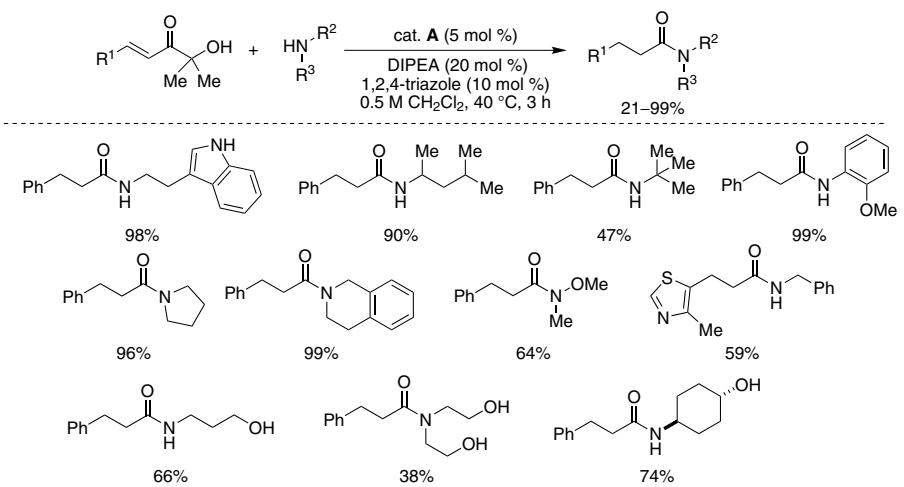
Scheme 24. Generations of Breslow intermediate from α'-hydroxyenones and enals.

These substrates are particularly well suited for the synthesis of cyclopentenes and lactams, with selected examples shown in **Scheme 25**. Due to the increased steric demands of the ketone substrates, these reactions work best with achiral triazolium precatalyst **A**. We therefore highly recommend these conditions for the preparation of racemic mixtures and the preparation of small libraries. Should the enantiopure compounds be needed, they can be prepared with chiral catalysts **B** and ***ent*-B** from the α,β-unsaturated aldehyde.



Scheme 25. NHC catalyzed annulations using α'-hydroxyenones.

The α'-hydroxyenones are also outstanding substrates for NHC-catalyzed amidations in combination with 1,2,4-triazole as a co-catalyst.[43] Unlike most amidation conditions that require excess amounts of coupling reagents and generate a large amount of waste, these conditions affect catalytic amidations with no products other than acetone and only substoichiometric quantities of reagents. Selected examples are shown in **Scheme 26**.



Scheme 26. Catalytic amidation with α'-hydroxyenones.

9 Conclusions

In just four years since the initial report, *N*-mesityl substituted chiral triazolium salts have proven to be one of the most versatile and selective catalysts known. In addition to the remarkable range of products they may be used to construct, they are notable for their high stability, mild reaction conditions (20–40 °C), and tolerance to air and water. A single chiral catalysts work well for nearly all of the reactions reported to date. For a few NHC-catalyzed reactions for which **B** and ***ent*-B** give inferior enantioselectivities, a number of new chiral scaffolds are emerging. Notable, all of these structures maintain the essential *N*-mesityl triazolium core that has proved to be necessary for both reactivity and selectivity in these new generations of N-heterocyclic carbene catalyzed reactions. The commercial availability of these catalysts should encourage the discovery of even more new reactions and applications of the complex, enantiopure products they afford.

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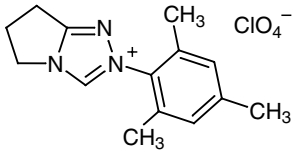
[Specialties] Chemistry, Organic Synthesis, Asymmetric Catalysis Chemistry, Peptide Chemistry

寄稿論文　TCI 関連製品

Bode 試薬



6,7-Dihydro-2-(2,4,6-trimethylphenyl)-
5*H*-pyrrolo[2,1-*c*]-1,2,4-triazolium Perchlorate
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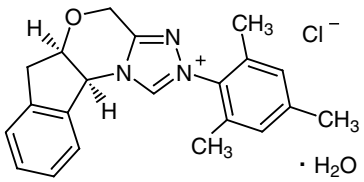
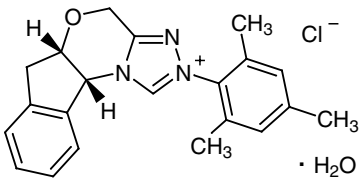


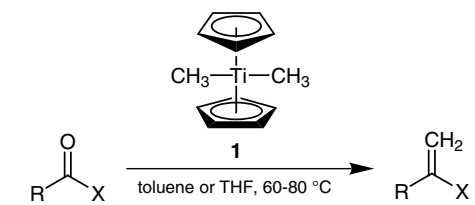
(+)-(5a*R*,10b*S*)-5a,10b-Dihydro-2-(2,4,6-trimethyl-
phenyl)-4*H*,6*H*-indeno[2,1-*b*][1,2,4]triazolo-
[4,3-*d*][1,4]oxazinium Chloride Monohydrate
100mg 13,900 円 [D3983]



(-)-(5a*S*,10b*R*)-5a,10b-Dihydro-2-(2,4,6-trimethyl-
phenyl)-4*H*,6*H*-indeno[2,1-*b*][1,2,4]triazolo-
[4,3-*d*][1,4]oxazinium Chloride Monohydrate
100mg 13,900 円 [D3984]

Petasis 試薬 / Petasis Reagent

D3956 Dimethyltitanocene (5% in Toluene) (1)　100g 25,500 円



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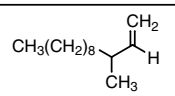
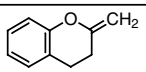
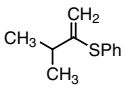
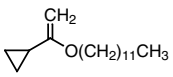
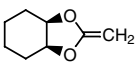
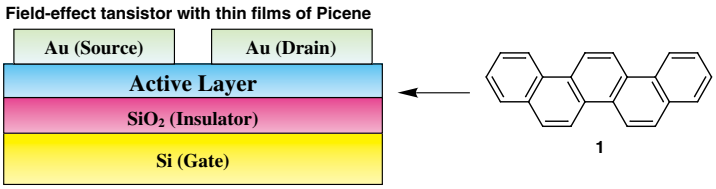
	62		80
	90		68
	87		65

ジメチルチタノセン（**1**）は Petasis 試薬とも呼ばれる有用なメチレン化試薬です。**1** は 60 ℃以上で熱分解してチタノセンーメチリデン活性種を生成し，アルデヒド，ケトン，エステル，ラクトンなどの種々のカルボニル化合物と反応し，対応するオレフィンを与えます。**1** は Tebbe 試薬に比べて空気中で安定な上，ルイス酸性の強いアルミニウムを含まず，温和な条件下で反応が進行します。Tebbe 試薬と相補的にご利用ください。

文献
1) Methylenations of carbonyl compounds with dimethyltitanocene
a) N. A. Petasis, E. I. Bzowej, *J. Am. Chem. Soc.* **1990**, *112*, 6392. b) N. A. Petasis, S.-P. Lu, E. I. Bzowej, D.-K. Fu, J. P. Staszewski, I. Akritopoulou-Zanze, M. A. Patane, Y.-H. Hu, *Pure & Appl. Chem.* **1996**, *68*, 667.

新しい有機機能性材料（ピセン）/ New Organic Functional Material (Picene)

P1893 Picene (purified by sublimation) (1) 100mg 19,300円 1g 115,800円



1

T_c values / metal (K and Rb) and the doping rate

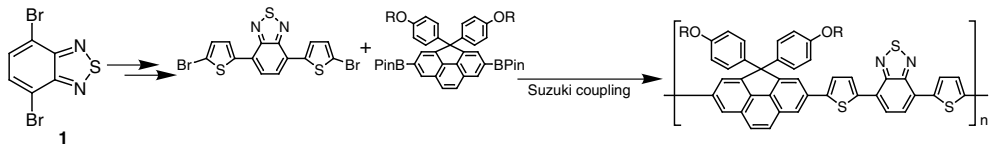
Alkali metal (M)	Metal content (M / 1)	T_c (K)
K	2.9	7
K	**3.3**	**18**
Rb	3.1	7

ピセン（**1**）は，ベンゼン環５個がW型に縮環した芳香族炭化水素化合物です。久保園らはピセンが有機電解効果トランジスタの活性層として極めて高い特性を示すことを報告しています[1]。電解効果移動度は1.1 $cm^2V^{-1}s^{-1}$と極めて高く，さらに70時間酸素暴露後には，移動度が1.75 $cm^2V^{-1}s^{-1}$まで向上し，高性能トランジスタとしての応用が期待されています。また，久保園らは**1**にカリウムを3.3等量注入した際，18 K（-255 °C）で超伝導転移が発現することも報告しており[2]，これは有機分子の転移温度としては極めて高い温度です。今後もピセンを用いた応用研究が期待されます。

文献
1) Air-assisted high-performance field-effect transistor with thin films of picene
H. Okamoto, N. Kawasaki, Y. Kaji, Y. Kubozono, A. Fujiwara, M. Yamaji, *J. Am. Chem. Soc.* **2008**, *130*, 10470.
2) Superconductivity in alkali-metal-doped picene
R. Mitsuhashi, Y. Suzuki, Y. Yamanari, H. Mitamura, T. Kambe, N. Ikeda, H. Okamoto, A. Fujiwara, M. Yamaji, N. Kawasaki, Y. Maniwa, Y. Kubozono, *Nature* **2010**, *464*, 76.

有機薄膜太陽電池材料合成用ビルディングブロック / Building Block for Organic Photovoltaic Cell Polymers

D3842 4,7-Dibromo-2,1,3-benzothiadiazole (1) 1g 8,000円 5g 24,000円 25g 58,000円



2,1,3-ベンゾチアジアゾールは電子不足系芳香族分子として知られています。そのLUMOエネルギーの低さから，電子豊富な分子と共重合させることにより，エネルギーバンドギャップの極めて小さいポリマーを得ることができます。近年，有機薄膜太陽電池材料としてベンゾチアジアゾール部位を有する共重合ポリマーの研究が盛んに行われています。例えば，Kimらは，**1**を原料に用い，電子豊富なフェナントレン誘導体との共重合体を合成しています。この共重合体と$PC_{71}BM$から成るバルクヘテロ接合型太陽電池素子は，エネルギー変換効率1.12%を達成しています。

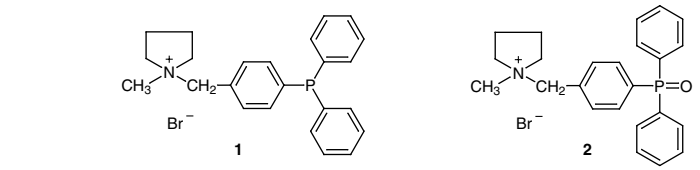
文献
Low-bandgap poly(4*H*-cyclopenta[*def*]phenanthrene) derivatives with 4,7-dithienyl-2,1,3-benzothiadiazole unit for photovoltaic cells
J. Kim, S. H. Park, S. Cho, Y. Jin, J. Kim, I. Kim, J. S. Lee, J. H. Kim, H. Y. Woo, K. Lee, H. Suh, *Polymer* **2010**, *51*, 390.

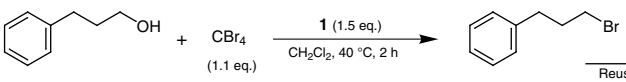
イオン固定型トリフェニルホスフィン / Ion-supported Triphenylphosphine

M2103 1-Methyl-1-[4-(diphenylphosphino)benzyl]pyrrolidinium Bromide (1) 1g 21,000 円

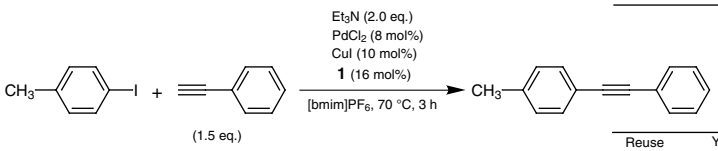
1- メチル -1-[4-(ジフェニルホスフィノ)ベンジル]ピロリジニウムブロミド（**1**）は，東郷らが開発した空気中で安定なイオン固定型トリフェニルホスフィンです。**1** を用いたアルコールのハロゲン化，光延反応によるカルボン酸のエステル化では，副生するホスフィンオキシド **2** がエーテルに溶けにくいため，反応終了後，生成物をエーテル抽出してろ過することにより，90% 以上の回収率で **2** を容易に分離することができます。**2** はジメチル硫酸による *O*-メチル化，$LiAlH_4$ による還元により **1** を再生し，再利用することが可能です。

また，**1** は溝呂木ーヘック反応や薗頭反応などの金属触媒の配位子としても有用です。**1** およびパラジウム触媒を含むイオン液体反応溶媒は再利用することが可能で，繰り返し用いても高収率を維持します。





Reuse	Yields (%)	
	1	Ph_3P
0	95	68
1	93	-
2	87	-



Reuse	Yields (%)	
	1	Ph_3P
0	100	91
1	100	92
2	100	99
3	100	76
4	100	41
5	90	18
6	95	-
7	94	-

実験例： アルコールの臭素化

1 (1320 mg, 3.0 mmol) を真空ポンプで 70 ℃で 2 時間乾燥させる。**1** を入れたフラスコに 3- フェニル -1- プロパノール (272 mg, 2.0 mmol) と四臭化炭素 (729 mg, 2.2 mmol) のジクロロメタン (6 mL) 溶液を加え，アルゴン雰囲気下，40 ℃で 2 時間撹拌する。反応終了後，エーテル (10 mL) を加え，室温で 40 分撹拌する。ろ過し，エーテルで洗浄した後，ろ液を溶媒留去することにより，粗製が得られる（純度 70-75%，副生成物 $CHBr_3$ を含む）。シリカゲルのショートカラムクロマトグラフィー（クロロホルム）で精製することにより，純粋な 3- フェニル -1- ブロモプロパンが得られる。副生成物 **2** はろ液から 93% 回収される。

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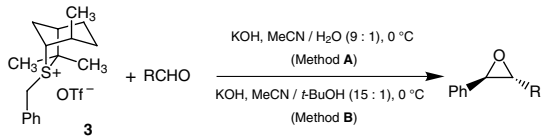
1) Ion-supported triphenylphosphines and their synthetic utility
Y. Imura, N. Shimojuh, Y. Kawano, H. Togo, *Tetrahedron* **2010**, *66*, 3421.

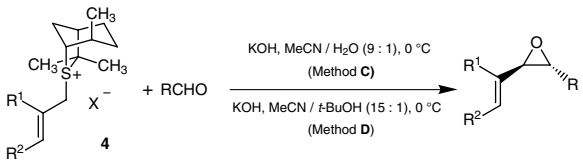
硫黄イリドによるキラルオキシラン合成で有用な不斉補助剤 / Useful Chiral Auxiliaries for the Synthesis of Chiral Oxiranes

T2578 (1*R*,4*R*,5*R*)-4,7,7-Trimethyl-6-thiabicyclo[3.2.1]octane (1) 1g 6,700円 5g 19,900円
T2579 (1*S*,4*S*,5*S*)-4,7,7-Trimethyl-6-thiabicyclo[3.2.1]octane (2) 1g 8,300円 5g 25,000円

Aggarwal らは，(1*R*,4*R*,5*R*)-4,7,7-トリメチル-6-チアビシクロ [3.2.1] オクタン（**1**）から誘導したスルホニウム塩 **3** および **4** を塩基で処理して得られる硫黄イリドを用いた不斉合成を報告しています。それによれば，**3** とアルデヒドおよびイミンとの反応で，キラルフェニルオキシラン，アジリジン類が，また **4** とアルデヒドとの反応では，キラル α,β- 不飽和オキシランがそれぞれ高収率・高不斉収率で得られます。さらに Aggarwal らはこの手法を用いたアルカロイド類の全合成も報告しています。**1** および **2** は種々の不斉硫黄イリドへの誘導が可能で，キラルオキシラン，アジリジンの合成に幅広く適用できる有用な不斉補助剤です。

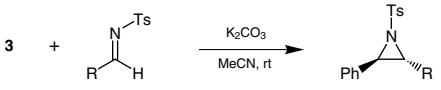


R	Method	Yield (%)	*d.r.*	*e. r.*
Ph	**A**	77	>95 : 5	99 : 1
(*E*)-PhCH=C(Me)	**A**	84	>95 : 5	98 : 2
c-C_6H_{11}	**B**	62	93 : 7	99 : 1
n-C_4H_9	**B**	56	91 : 9	99 : 1

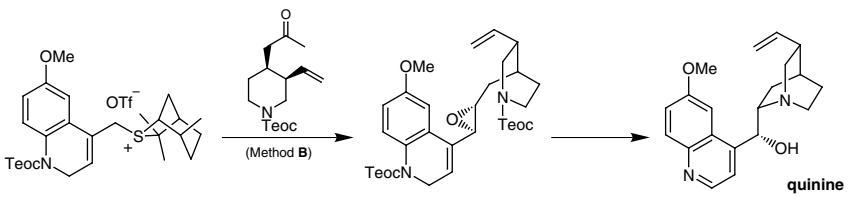


R^1	R^2	R	Method	Yield (%)	*d.r.*	*e. r.*
Me	Ph	Ph	**C**[a]	97	>95 : 5	99 : 1
Me	H	Ph	**C**[b]	80	>95 : 5	99 : 1
Me	Ph	*c*-C_6H_{11}	**D**[a]	77	>95 : 5	98 : 2
Me	H	*c*-C_6H_{11}	**D**[b]	77	>95 : 5	97 : 3

[a] X = BF_4. [b] X = OTf.



R	Yield (%)	*trans/cis*	*e. r.*
Ph	72	85 : 15	99 : 1
p-ClC_6H_4	65	75 : 25	99 : 1
p-$MeOC_6H_4$	80	83 : 17	99 : 1
(*E*)-PhCH=CH	78	>99 : 1	98 : 2



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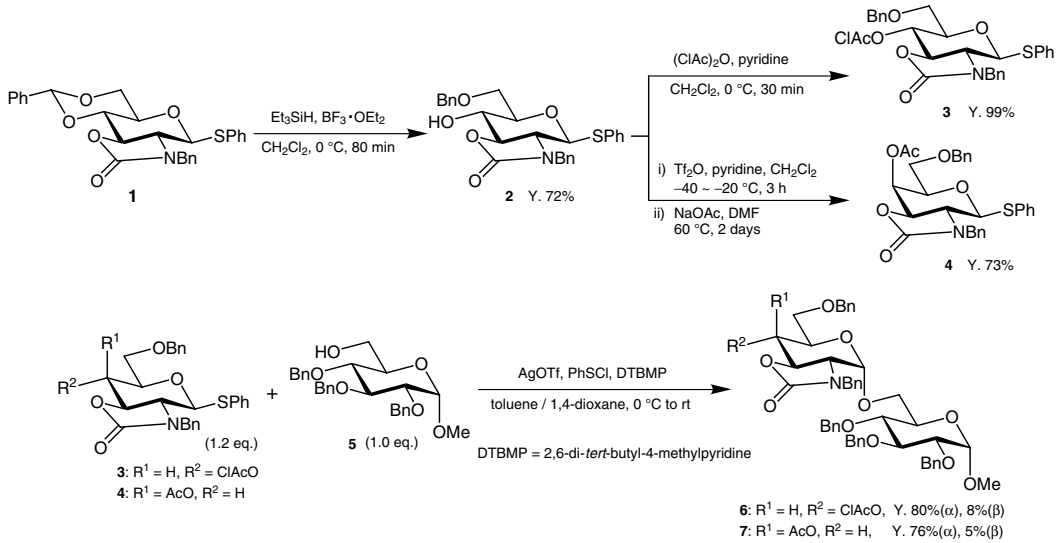
1) Practical and highly selective sulfur ylide mediated asymmetric epoxidations and aziridinations using an inexpensive, readily available chiral sulfide
O. Illa, M. Arshad, A. Ros, E. M. McGarrigle, V. K. Anggarwal, *J. Am. Chem. Soc.* **2010**, *132*, 1828.

糖供与体 / Glycosyl Donor

P1762 Phenyl *N*-Benzyl-2-amino-4,6-*O*-benzylidene-2-*N*,3-*O*-carbonyl-2-deoxy-1-thio-β-D-glucopyranoside (1)

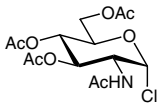
1g 39,900 円



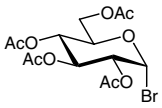
フェニル*N*-ベンジル-2-アミノ-4,6-*O*-ベンジリデン-2-*N*,3-*O*-カルボニル-2-デオキシ-1-チオ-β-D-グルコピラノシド（**1**）は真鍋らが開発した糖供与体で，アミノ糖の1,2-*cis*グリコシド結合の合成ブロックとして用いられます。例えば，**1**はベンジリデン部位を還元開裂した後，４位をクロロアセチル化してグルコサミン誘導体**3**に，あるいは４位のヒドロキシ基を立体反転させアセチル化してガラクトサミン誘導体**4**に導くことができます。この**3**，**4**は，それぞれ糖受容体**5**と反応し，高いα選択性を持って1,2-*cis*グリコシド結合を有する二糖**6**，**7**を与えます。1,2-*cis*グリコシド結合を有するアミノ糖は，ヘパリンなどの生理活性を持つ糖鎖に多く見られるため，これらの糖鎖合成への応用が期待されます。

文献
1) Selective α-glycosylation and one-pot oligosaccharide synthesis involving 1,2-*cis*-glycosylation
S. Manabe, K. Ishii, Y. Ito, *J. Am. Chem. Soc.* **2006**, *128*, 10666.

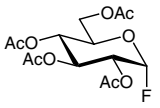
糖供与体 / Glycosyl Donors



2-Acetamido-3,4,6-tri-*O*-acetyl-2-deoxy-α-D-glucopyranosyl Chloride
1g 7,300 円 5g 21,600 円 [A1416]



2,3,4,6-Tetra-*O*-acetyl-α-D-glucopyranosyl Bromide (stabilized with $CaCO_3$)
5g 7,800 円 [T1961]



2,3,4,6-Tetra-*O*-acetyl-α-D-glucopyranosyl Fluoride
1g 18,000 円 [T1995]

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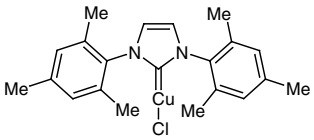
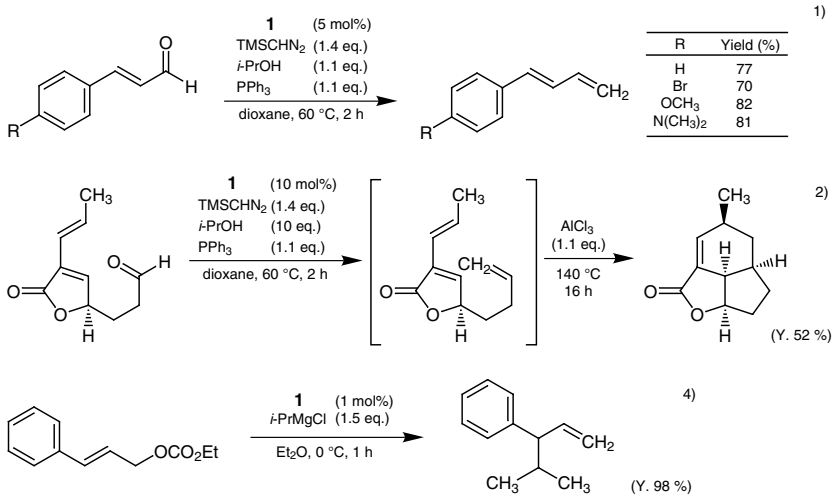
(IMes)-銅錯体触媒を用いるメチレン化反応と Grignard 反応 / (IMes)-Copper Complex for Methylenation and Grignard Reactions

C2422 Chloro(1,3-dimesitylimidazol-2-ylidene)copper(I) (1) 200mg 5,000円 1g 13,000円

クロロ(1,3-ジメシチルイミダゾール-2-イリデン)銅(I) (**1**) は種々の脂肪族と芳香族のアルデヒドとケトンのメチレン化反応に用いられる有用な触媒で，トリメチルシリルジアゾメタンとトリフェニルホスフィンの存在下で使用されています[1]。このメチレン化反応はワンポットのメチレン化ーDiels-Alder環化反応や[2]，ワンポットのメチレン化ー分子内Heck反応に利用されています[3]。**1** はGrignard試薬を用いるアリル置換反応の触媒としても用いられています[4]。



1
(IMes)-Cu complex



実験例 [1] (R = H)：
錯体 **1** (20.2 mg, 0.050 mmol) とトリフェニルホスフィン (288 mg, 1.10 mmol) の 25 ℃のジオキサン溶液 (10 mL) に 2- プロパノール (84 µL, 1.1 mmol)，ついで *trans*- シンナムアルデヒド (125 µL, 1.00 mmol) とトリメチルシリルジアゾメタン溶液 (1.4-2.0 mmol) を不活性ガス雰囲気下で加える。反応溶液を 60 ℃で 2 時間反応する。その後に 3% 過酸化水素水 (10 mL) を加え，有機層をエーテル (3 × 20 mL) で抽出する。有機層を合一して飽和食塩水 (2 × 20 mL) で洗浄し，硫酸マグネシウムで乾燥する。ろ液を減圧濃縮して得られる残渣をフラッシュシリカゲルクロマトグラフィー（ヘキサン：酢酸エチル = 99：1）で精製することにより，1- フェニル -1,3- ブタジエン (100 mg, Y. 77%) の無色油状物質が得られる。

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Copper-catalyzed methylenation reaction
1) H. Lebel, M. Davi, S. Díez-González, S. P. Nolan, *J. Org. Chem.* **2007**, *72*, 144.
2) H. Lebel, M. Parmentier, *Org. Lett.* **2007**, *9*, 3563.
3) H. Lebel, C. Ladjel, L. Bréthous, *J. Am. Chem. Soc.* **2007**, *129*, 13321.
4) S. Okamoto, S. Tominaga, N. Saino, K. Kase, K. Shimoda, *J. Organomet. Chem.* **2005**, *690*, 6001.

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