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Copper and Rhodium Relay Catalysis for Selective Access to *cis*-2,3-Dihydroazepines

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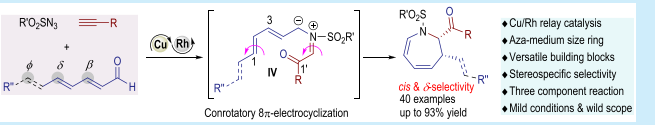
ABSTRACT: A new catalytic protocol to access synthetically challenging *cis*-2,3-dihydroazepines is reported. The reaction starts with readily available dienals, alkynes, and sulfonyl azides as the substrates and employs copper and rhodium as relay catalysts. Key steps include a copper-catalyzed reaction between an alkyne and a sulfonyl azide to form a triazole intermediate. The subsequent activation of this triazole intermediate by a rhodium catalyst, followed by a reaction with the dienal substrate, eventually leads to the dihydroazepine product. The regio- and stereochemistries of the products are believed to be controlled through a stereospecific conrotatory 8π-electrocyclization process against a possible competing 6π-electrocyclization process.



Nitrogen-containing heterocycles are common scaffolds in numerous functional molecules.[1] In particular, the azepine derivatives, such as dihydroazepines, are important core structures that are found in natural products and pharmaceuticals (Figure 1a).[2] The preparations of these azepine derivatives are significantly more challenging than those of their five- or six-membered analogs. Indeed, efficient routes to the synthesis of nitrogen-containing heterocycles with medium-sized rings are not particularly common.[3] In addition, the stereoselectivities of the substituents are difficult to control due to medium-sized compounds being more flexible than their five- or six-membered analogs, especially when thermodynamically unfavorable isomers are the desired products.

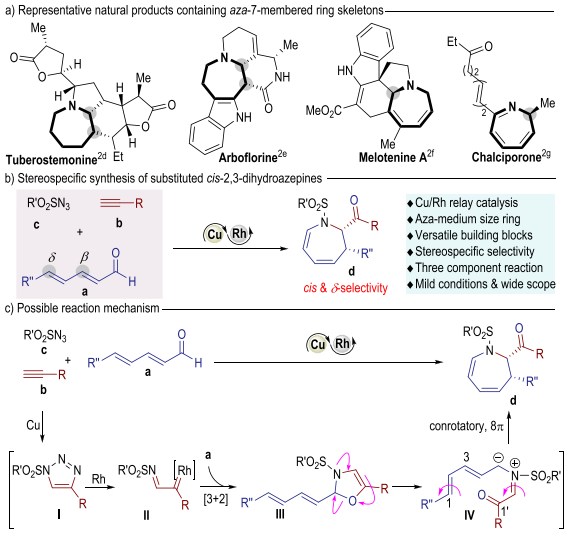


Figure 1. Representative natural products and our proposal strategy.

As convenient α-imino diazo precursors, *N*-sulfonyl-1,2,3-triazoles[4] offer great opportunities for the construction of nitrogen-containing heterocycles.[5] Recently, Fokin[6a] and Murakami[6b] reported two compelling cycloaddition reactions that form five-membered oxazolines and pyrroles using triazoles as α-imino carbene precursors, respectively. We envisioned that the three-component cascade reaction of a di- or trienal (**a**), an alkyne (**b**), and a sulfonyl azide (**c**) would provide quick access to *cis*-substituted 2,3-dihydroazepines in the presence of Cu or Rh (Figure 1b). However, it has been published that metal carbene precursors reacted with dienes to yield azepine structural units.[7] Our method can provide an expeditious path for the divergent synthesis of *cis*-2,3-dihydroazepines. One potential challenge in achieving our proposed reaction is controlling the diastereoselectivity to selectively obtain *trans*- or *cis*-substituted 2,3-dihydroazepine products. Another challenge involves regioselectivity (β vs δ) issues that lead to the formation of undesired five-membered ring products, especially when enals devoid of substituents at their β-carbon atoms are employed.

The design of our reaction is further elaborated in Figure 1c. Initially, the copper-catalyzed reaction of a sulfonyl azide and an alkyne generates the *N*-sulfonyl-1,2,3-triazole **I**.[8] The triazole then serves as an α-imino diazo precursor to provide a metal-stabilized carbenoid under the catalysis of Rh(II).[9] The

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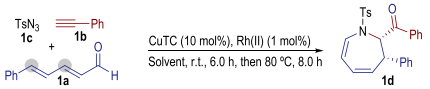
reaction of carbenoid **II** with an aldehyde carbonyl group then generates the oxazoline **III** through a formal [3 + 2] cycloaddition. The selective thermal cleavage of the oxazoline C−O bond subsequently leads to the formation of the isoelectronic intermediate **IV**. According to the Woodward−Hoffmann rules,[10] the intermediate **IV** was expected to undergo conrotatory 8π-electrocyclizaitons to afford a new seven-membered ring product **d** bearing substituents with a specific stereochemistry. The competing chemo- and regioselectivities might be fully suppressed in this cyclization process. Herein we report our results on the stereospecific synthesis of *cis*-substituted 2,3-dihydroazepines via a relay Cu- and Rh-catalyzed cascade reaction of TsN_3, alkynes, and enals.

To test the feasibility of our proposed strategy, we used CuTC and $Rh_2(Oct)_4$ as the relay catalysts for the cascade reaction of dienal **1a**, phenylacetylene **1b**, and TsN_3 **1c** (Table 1). More specifically, after **1b** was fully transformed into the

Table 1. Optimization of the Reaction Conditions[a]



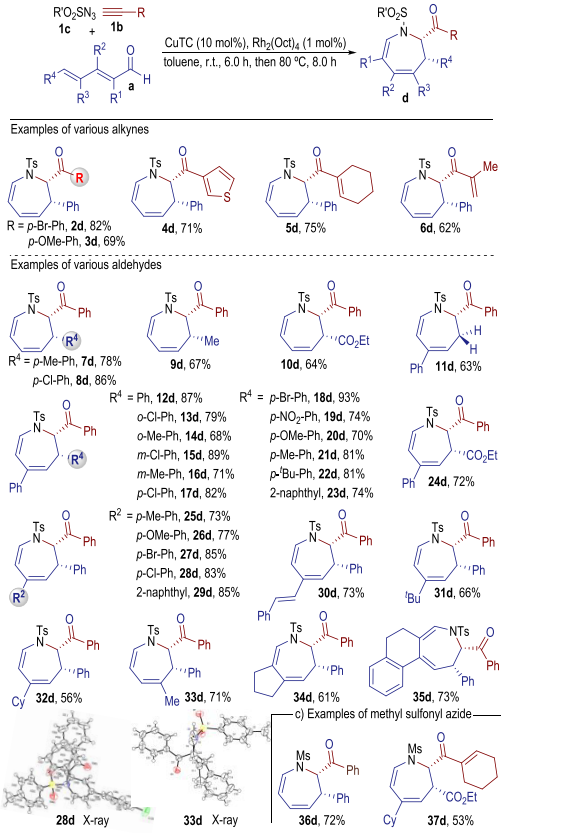
entry	catalyst	solvents	yields (%)[b]
1	$Rh_2(Oct)_4$	chloroform	72
2	$Rh_2(Oct)_4$	1,2-DCE	49
3	$Rh_2(Oct)_4$	DCM	66
4	$Rh_2(Oct)_4$	benzotrifluoride	47
5	$Rh_2(Oct)_4$	chlorobenzene	62
6	**$Rh_2(Oct)_4$**	**toluene**	**81 (75)**81 (75)[c]
7	$Rh_2(OAc)_4$	toluene	51
8	$Rh_2(TFA)_4$	toluene	46
9	$Rh_2(esp)_2$	toluene	51
10		toluene	0
11[d]	$Rh_2(Oct)_4$	toluene	0

[a]All reactions of **1a** (0.1 mmol), **1b** (0.15 mmol), and **1c** (0.2 mmol) were performed in the presence of CuTC (10 mol %) and Rh(II) (1 mol %) in 1.0 mL of solvent at room temperature for 6.0 h, after which the reaction mixture was heated at 80 °C in an oil bath for 8.0 h. [b]Isolated yield. [c]The mixture was directly reacted at 80 °C for 8.0 h. [d]Without CuTC. CuTC, copper(I) thiophene-2-carboxylate hydrate; $Rh_2(Oct)_4$, rhodium(II) octanoate dimer; $Rh_2(OAc)_4$,r hodium(II) acetate dimer; $Rh_2(TFA)_4$,r hodium(II) trifluoroacetate dimer; $Rh_2(esp)_2$, bis[rhodium($\alpha,\alpha,\alpha',\alpha'$-tetramethyl-1,3-benzenedipropionic acid)].

triazole at room temperature (r.t.), the resulting mixture was reacted at 80 °C for 8.0 h. As anticipated, the reaction afforded the desired *cis*-substituted 2,3-dihydroazepine **1d** in a range of solvents (Table 1, entries 1−6). Various Rh(II) catalysts (Table 1, entries 7−9) were subsequently investigated, and $Rh_2(Oct)_4$ was found to be the best choice in terms of reactivity (81% yield; Table 1, entry 6). When the mixture was directly reacted at 80 °C, the reaction also successfully afforded the desired product, albeit in a lower yield (Table 1, entry 6). Further control experiments indicate that the both Cu(I) and Rh(II) as cocatalysts are essential for the transformation (Table 1, entries 10 and 11). Additionally, we treated enal **1a** and N^1-tosyl-1,2,3-triazole with the Rh catalyst at 80 °C in toluene, to obtain **1d** in an 87% yield.[11] This result further demonstrated the Rh is the catalyst for the formation of intermediate **III** rather than copper.

Having established the optimal reaction conditions, the substrate scope of the transformation was next examined using a range of dienals, alkynes, and sulfonyl azides (Table 2).

Table 2. Substrate Scope[a,b]



[a]Reactions were performed according to a one-pot protocol using the standard conditions unless otherwise noted. [b]Isolated yield.

Initially, a series of terminal alkynes **b** were examined to react with δ-phenyl dienal **1a** and TsN_3 **1c**. Aryl alkynes provided the products **2d−4d** in high yields. Replacing the aromatic unit with alkenyl groups also gave the desired products **5d** and **6d** in good yields. The alkyl-substituted alkynes, such as cyclohexylacetylene and *t*-butyclethyne, were investigated, and the same reaction conditions resulted in a 1,2-alkyl migration reaction to afford α,β-unsaturated imines.[12]

To expand the scope of this reaction, we explored the reactivities of the substituted dienals under the optimal reaction conditions. Gratifyingly, a broad range of β-monosubstituted, δ-monosubstituted, and β,δ-disubstituted dienals worked well, furnishing the desired products in good yields (**7d−32d**). The dienals with δ-*p*-Me-phenyl, δ-*p*-Cl-phenyl, and δ-alkyl were investigated, affording the products **7d−9d** in high yields. In addition, the introduction of an ester moiety at the δ-position of the dienal substrate did not affect the reaction outcome (**10d**). Moreover, the δ-substituted dienal also gave the target product **11d** in a 63% yield. Subsequently, the β,δ-disubstituted dienals were investigated under our standard conditions (**12d−32d**). Among these substrates, the presence of the β-^{t}Bu and β-cyclohexyl substituents had a detrimental effect on the yields, decreasing those of the corresponding products to 66% and 56% (**31d** and **32d**), respectively. The dienal with γ,δ-disubstitutions was

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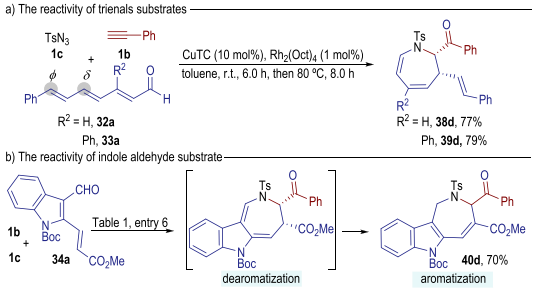
found to be amenable to the optimized reaction conditions, affording the product **33d** in a high yield, while the substrates bearing fused-rings at the α,β-positions of their dienal components afforded multicyclic products **34d** and **35d** in high yields. Switching the tosyl-azide to a mesyl-azide also led to the expected products (i.e., **36d** and **37d**) in good yields.

The relative configurations of the products could be assigned unambiguously by the NMR spectra and X-ray diffraction patterns (**28d** and **33d**). Generally, the reaction displayed a good functional group tolerance with single regio- and diastereoselectivities. In all cases, the competitive side products were not observed on the crude ^{1}H NMR spectra.

To test a possible 10π-electrocyclization process with the currently developed method in the formation of the nine-membered heterocycles, two trienals were subjected to the standard reaction conditions (Scheme 1a). However, all

Scheme 1. Investigating the Reactivity and Selectivity of Trienals and Indole Aldehyde

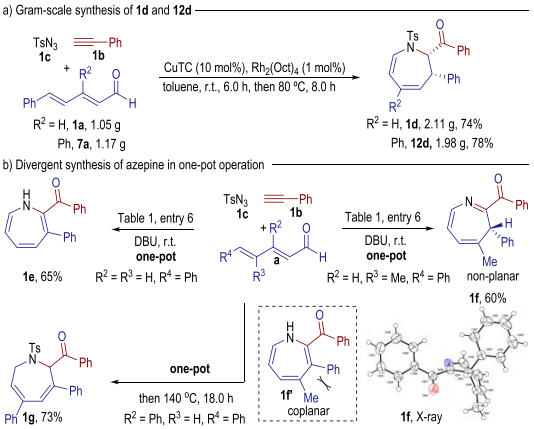


spectroscopic and analytical evidence suggested that the formation of a nine-membered product from a trienal through a 10π-electrocyclization reaction is not possible. The corresponding *cis*-substituted 2,3-dihydroazepine products (**38d** and **39d**) were afforded with exquisite site selectivities.

Furthermore, to expand the reaction mode to an aromatic system, the indole aldehyde **34a** bearing a multiple-conjugated enal structure was reacted under standard reaction conditions (Scheme 1b). To our delight, the reaction was amenable to the optimized reaction conditions, resulting in the formation of 2,7-dihydroazepine **40d** in a high yield. A sequential dearomatization and aromatization process might be involved in this transformation. As an overview of the results, the reactions of various enals, alkynes and azides worked well in a stereospecific manner. Although some mechanistic details of this reaction remain unclear and are the topic of further investigation, these stereospecific reaction results support an 8π-electrocyclizaiton mechanism.

To demonstrate the practical utility of the developed method, the gram-scale reactions of **1a** and **7a** were also carried out, deliveirng the corresponding products **1d** and **12d** in 74% and 78% yields, respectively (Scheme 2a). Next, the practical utility of this strategy was further demonstrated by the divergent synthesis of structurally significant nitrogen-containing seven-membered ring products (Scheme 2b). We deduced that the 1*H*-azepine **1e** might be formed from *cis*-substituted 2,3-dihydroazepines **1d** through the elimination of Ts in the presence of a base. As we expected, after converting the substrate **1a** into **1d**, the addition of DBU led to the 1*H*-azepine product **1e** at room temperature in a 65% yield. Interestingly, the X-ray structure suggested that the reaction of the γ,δ-disubstituted dienal substrate under the same condition

Scheme 2. Gram-Scale Synthesis and Divergent Synthesis of Azepines in a One-Pot Operation



afforded the substituted 3*H*-azepine product **1f** rather than the 1*H*-azepine product **1f′**. We consider that the 1*H*-azepine **1f′** might be a thermodynamically unstable structure due to the spatial repulsion between the coplanar methyl group and the phenyl group. Finally, after the β,δ-diphenyl-substituted dienal was fully converted to the corresponding product **12d**, increasing the temperature to 140 °C led to the isomerization of the diene structural unit via 1,5-hydrogen migration to give the more thermodynamically stable conjugated structure 2,7-dihydroazepine **1g**. In general, our transformations are practical and convenient for the construction of structurally diverse azepines with potential applications in the preparation of molecular libraries.

In summary, we have developed a three-component cascade reaction for accessing *cis*-substituted 2,3-dihydroazepines. This reaction proceeds through a stereospecific conrotatory 8π-electrocyclization process that controls the diastereo- and regioselectivities of the reaction. The possible competing 6π-electrocyclization reactions are fully suppressed in all cases. Attractively, the *cis*-substituted 2,3-dihydroazepines could serve as platform building blocks for the divergent synthesis of various azepines via tunable one-pot routes. In particular, complex polycyclic products can also be selectively obtained using our cascade reaction as the key step.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.orglett.1c02262.

General procedures, characterization and X-ray data, and NMR spectra (PDF)

Accession Codes

CCDC 1583678, 1866403, and 1951627 contain the supplementary crystallographic data for this paper. These data can be obtained free of charge via www.ccdc.cam.ac.uk/data_request/cif, or by emailing data_request@ccdc.cam.ac.uk, or by contacting The Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK; fax: +44 1223 336033.

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Author Contributions

‡Y.L. and H.L. contributed equally to this work.

Notes

The authors declare no competing financial interest.

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REFERENCES

(1) (a) Shirota, Y.; Kageyama, H. Charge Carrier Transporting Molecular Materials and Their Applications in Devices. *Chem. Rev.* **2007**, *107*, 953−1010. (b) Walzer, K.; Maennig, B.; Pfeiffer, M.; Leo, K. Highly Efficient Organic Devices Based on Electrically Doped Transport Layers. *Chem. Rev.* **2007**, *107*, 1233−1271. (c) Yan, W.; Wang, Q.; Lin, Q.; Li, M.; Petersen, J. L.; Shi, X. N-2-Aryl-1,2,3-Triazoles: A New Class of UV-Blue Emitting Fluorophores with Tunable Optical Properties. *Chem. - Eur. J.* **2011**, *17*, 5011−5018. (d) Li, L.-L.; Diau, E. W.-G. Porphyrin-sensitized solar cells. *Chem. Soc. Rev.* **2013**, *42*, 291−304.

(2) For selected reviews, see: (a) Wang, Y.-Z.; Tang, C.-P.; Dien, P.-H.; Ye, Y. Alkaloids from the Roots of Stemona saxorum. *J. Nat. Prod.* **2007**, *70*, 1356−1359. (b) Mungkornasawakul, P.; Chaiyong, S.; Sastraruji, T.; Jatisatienr, A.; Jatisatienr, C.; Pyne, S. G.; Ung, A. T.; Korth, J.; Lie, W. Alkaloids from the Roots of *Stemona aphylla*. *J. Nat. Prod.* **2009**, *72*, 848−851. (c) Lindsay, A. C.; Kim, S. H.; Sperry, J. Non-monoterpenoid azepinoindole alkaloids. *Nat. Prod. Rep.* **2018**, *35*, 1347−1382. For Tuberostemonine, see: (d) Götz, M.; Bögri, T.; Gray, A. H.; Strunz, G. M. The structure of tuberostemonine. *Tetrahedron* **1968**, *24*, 2631−2643. For arboflorine, see: (e) Lim, K.-H.; Kam, T.-S. Arboflorine, an Unusual Pentacyclic Monoterpenoid Indole Alkaloid Incorporating a Third Nitrogen Atom. *Org. Lett.* **2006**, *8*, 1733−1735. For melotenine A, see: (f) Feng, T.; Li, Y.; Liu, Y.-P.; Cai, X.-H.; Wang, Y.-Y.; Luo, X.-D. Melotenine A, a Cytotoxic Monoterpenoid Indole Alkaloid from *Melodinus tenuicaudatus*. *Org. Lett.* **2010**, *12*, 968−971. For chalciporone, see: (g) Sterner, O.; Steffan, B.; Steglich, W. Novel azepine derivatives from the pungent mushroom chalciporone Piperatus. *Tetrahedron* **1987**, *43*, 1075−1082.

(3) (a) Wender, P. A.; Pedersen, T. M.; Scanio, M. J. C. Transition Metal-Catalyzed Hetero-[5 + 2] Cycloadditions of Cyclopropyl Imines and Alkynes: Dihydroazepines from Simple, Readily Available Starting Materials. *J. Am. Chem. Soc.* **2002**, *124*, 15154−15155. (b) Shapiro, N. D.; Toste, F. D. Synthesis of Azepines by a Gold-Catalyzed Intermolecular [4 + 3]-Annulation. *J. Am. Chem. Soc.* **2008**, *130*, 9244−9245. (c) Zhou, M.-B.; Song, R.-J.; Wang, C.-Y.; Li, J.-H. Synthesis of Azepine Derivatives by Silver-Catalyzed [5 + 2] Cycloaddition of g-Amino Ketones with Alkynes. *Angew. Chem., Int. Ed.* **2013**, *52*, 10805−10808. (d) Vo, C.-V. T.; Luescher, M. U.; Bode, J. W. SnAP reagents for the one-step synthesis of medium-ring saturated N-heterocycles from aldehydes. *Nat. Chem.* **2014**, *6*, 310−314. (e) Zhou, M.-B.; Song, R.-J.; Li, J.-H. Hexafluoroantimonic Acid Catalysis: Formal [3 + 2+2] Cycloaddition of Aziridines with Two Alkynes. *Angew. Chem., Int. Ed.* **2014**, *53*, 4196−4199. (f) Feng, J. J.; Lin, T.-Y.; Wu, H.-H.; Zhang, J. Transfer of Chirality in the Rhodium-Catalyzed Intramolecular Formal Hetero-[5 + 2] Cycloaddition of Vinyl Aziridines and Alkynes: Stereoselective Synthesis of Fused Azepine Derivatives. *J. Am. Chem. Soc.* **2015**, *137*, 3787−3790. (g) Zuo, Z.; Liu, J.; Nan, J.; Fan, L.; Sun, W.; Wang, Y.; Luan, X. Highly Stereoselective Synthesis of Imine-Containing Dibenzo-[*b*,*d*]azepines by a Palladium(II)-Catalyzed [5 + 2] Oxidative Annulation of o-Arylanilines with Alkynes. *Angew. Chem., Int. Ed.* **2015**, *54*, 15385−15389. (h) Feng, J. J.; Lin, T.-Y.; Wu, H.-H.; Zhang, J. Modular Access to the Stereoisomers of Fused Bicyclic Azepines: Rhodium-Catalyzed Intramolecular Stereospecific Hetero-[5 + 2] Cycloaddition of Vinyl Aziridines and Alkenes. *Angew. Chem., Int. Ed.* **2015**, *54*, 15854−15858. (i) Li, T.; Xu, F.; Li, X.; Wang, C.; Wan, B. Ruthenium-Catalyzed C−C Bond Cleavage of 2*H*-Azirines: A Formal [3 + 2+2] Cycloaddition to Fused Azepine Skeletons. *Angew. Chem., Int. Ed.* **2016**, *55*, 2861−2865. (j) Feng, J. J.; Lin, T.-Y.; Zhu, C.-Z.; Wang, H.; Wu, H.-H.; Zhang, J. The Divergent Synthesis of Nitrogen Heterocycles by Rhodium(I)-Catalyzed Intermolecular Cycloadditions of Vinyl Aziridines and Alkynes. *J. Am. Chem. Soc.* **2016**, *138*, 2178−2181. (k) Hu, C.; Song, R.-J.; Hu, M.; Yang, Y.; Li, J.-H.; Luo, S. [5 + 2] Cycloaddition of 2-(2-Aminoethyl)oxiranes with Alkynes via Epoxide Ring-Opening: A Facile Access to Azepines. *Angew. Chem., Int. Ed.* **2016**, *55*, 10423−10426. (l) Zhu, C.-Z.; Feng, J.-J.; Zhang, J. Rhodium(I)-Catalyzed Intermolecular Aza-[4 + 3] Cycloaddition of Vinyl Aziridines and Dienes: Atom-Economical Synthesis of Enantiomerically Enriched Functionalized Azepines. *Angew. Chem., Int. Ed.* **2017**, *56*, 1351−1355.

(4) (a) Davies, H. M. L.; Alford, J. S. Reactions of metallocarbenes derived from *N*-sulfonyl-1,2,3-triazoles. *Chem. Soc. Rev.* **2014**, *43*, 5151−5162. (b) Jiang, Y.; Sun, R.; Tang, X.-Y.; Shi, M. Recent Advances in the Synthesis of Heterocycles and Related Substances Based on α-Imino Rhodium Carbene Complexes Derived from *N*-Sulfonyl-1,2,3-triazoles. *Chem. - Eur. J.* **2016**, *22*, 17910−17924. (c) Huisgen, R.; Knorr, R.; Mobius, L.; Szeimies, G. 1.3-Dipolare Cycloadditionen, XXIII. Einige Beobachtungen zur Addition organischer Azide an CC-Dreifachbindungen. *Chem. Ber.* **1965**, *98*, 4014−4021. (d) Luo, H.; Tang, Z.; Wang, T.; Tian, Y.; Zhang, Y.; Li, Y.; Li, S.; Gong, Y.; Li, B. Regioselective N^1- and N^2-heterocycloalkylation of N^1-sulfonyl-1,2,3-triazoles. *Org. Chem. Front.* **2020**, *7*, 3727−3733.

(5) (a) Horneff, T.; Chuprakov, S.; Chernyak, N.; Gevorgyan, V.; Fokin, V. V. Rhodium-Catalyzed Transannulation of 1,2,3-Triazoles with Nitriles. *J. Am. Chem. Soc.* **2008**, *130*, 14972−14974. (b) Chuprakov, S.; Kwok, S. W.; Fokin, V. V. Transannulation of 1-Sulfonyl-1,2,3-triazoles with Heterocumulenes. *J. Am. Chem. Soc.* **2013**, *135*, 4652−4655. (c) Schultz, E. E.; Sarpong, R. Application of In Situ-Generated Rh-Bound Trimethylenemethane Variants to the Synthesis of 3,4-Fused Pyrroles. *J. Am. Chem. Soc.* **2013**, *135*, 4696−4699. (d) Parr, B. T.; Green, S. A.; Davies, H. M. L. Rhodium-

Catalyzed Conversion of Furans to Highly Functionalized Pyrroles. *J. Am. Chem. Soc.* **2013**, *135*, 4716−4718. (e) Spangler, J. E.; Davies, H. M. L. Catalytic Asymmetric Synthesis of Pyrroloindolines via a Rhodium(II)-Catalyzed Annulation of Indoles. *J. Am. Chem. Soc.* **2013**, *135*, 6802−6805. (f) Miura, T.; Funakoshi, Y.; Murakami, M. Intramolecular Dearomatizing [3 + 2] Annulation of α-Imino Carbenoids with Aryl Rings Furnishing 3,4-Fused Indole Skeletons. *J. Am. Chem. Soc.* **2014**, *136*, 2272−2275. (g) Chen, K.; Zhu, Z.-Z.; Zhang, Y.-S.; Tang, X.-Y.; Shi, M. Rhodium(II)-Catalyzed Intramolecular Cycloisomerizations of Methylenecyclopropanes with *N*-Sulfonyl 1,2,3-Triazoles. *Angew. Chem., Int. Ed.* **2014**, *53*, 6645−6649. (h) Shang, H.; Wang, Y.; Tian, Y.; Feng, J.; Tang, Y. The Divergent Synthesis of Nitrogen Heterocycles by Rhodium(II)-Catalyzed Cycloadditions of 1-Sulfonyl 1,2,3-Triazoles with 1,3-Dienes. *Angew. Chem., Int. Ed.* **2014**, *53*, 5662−5666. (i) Kim, C.-E.; Park, S.; Eom, D.; Seo, B.; Lee, P. H. Synthesis of Pyrroles from Terminal Alkynes, *N*-Sulfonyl Azides, and Alkenyl Alkyl Ethers through 1-Sulfonyl-1,2,3-triazoles. *Org. Lett.* **2014**, *16*, 1900−1903. (j) Ran, R.-Q.; He, J.; Xiu, S.-D.; Wang, K.-B.; Li, C.-Y. Synthesis of 3-Pyrrolin-2-ones by Rhodium-Catalyzed Transannulation of 1-Sulfonyl-1,2,3-triazole with Ketene Silyl Acetal. *Org. Lett.* **2014**, *16*, 3704−3707. (k) Schultz, E. E.; Lindsay, V. N. G.; Sarpong, R. Expedient Synthesis of Fused Azepine Derivatives Using a Sequential Rhodium(II)-Catalyzed Cyclopropanation/1-Aza-Cope Rearrangement of Dienyltriazoles. *Angew. Chem., Int. Ed.* **2014**, *53*, 9904−9908. (l) Ma, X.; Pan, S.; Wang, H.; Chen, W. Rhodium-Catalyzed Transannulation of N-Sulfonyl-1,2,3-triazoles and Epoxides: Regioselective Synthesis of Substituted 3,4-Dihydro-2H-1,4-oxazines. *Org. Lett.* **2014**, *16*, 4554−4557. (m) Wang, Y. H.; Lei, X. Q.; Tang, Y. F. Rh(II)-catalyzed Cycloadditions of 1-Tosyl 1,2,3-Triazoles with 2H-Azirines: Switchable Reactivity of Rh-azavinylcarbene as [2C]- or Aza-[3C]-Synthon. *Chem. Commun.* **2015**, *51*, 4507−4510. (n) Lei, X. Q.; Li, L. B.; He, Y. P.; Tang, Y. F. Rhodium(II)-Catalyzed Formal [3 + 2] Cycloaddition of N-Sulfonyl-1,2,3-triazoles with Isoxazoles: Entry to Polysubstituted 3 Aminopyrroles. *Org. Lett.* **2015**, *17*, 5224−5227. (o) Li, Y.; Zhang, Q.; Du, Q.; Zhai, H. Rh-Catalyzed [3 + 2] Cycloaddition of 1-Sulfonyl-1,2,3-triazoles: Access to the Framework of Aspidosperma and Kopsia Indole Alkaloids. *Org. Lett.* **2016**, *18*, 4076−4079. (p) Dai, H.; Yu, S.; Cheng, W.; Xu, Z.-F.; Li, C.-Y. Rhodium-catalyzed synthesis of 1,2-dihydropyridine by a tandem reaction of 4-(1-acetoxyallyl)-1-sulfonyl-1,2,3-triazole. *Chem. Commun.* **2017**, *53*, 6417−6420. (q) Bosmani, A.; Guarnieri-Ibáñez, A.; Goudedranche, S.; Besnard, C.; Lacour, J. Polycyclic Indoline-Benzodiazepines through Electrophilic Additions of α-Imino Carbenes to Tröger Bases. *Angew. Chem., Int. Ed.* **2018**, *57*, 7151−7155. (r) Vaitla, J.; Boni, Y. T.; Davies, H. M. L. *Angew. Chem., Int. Ed.* **2020**, *59*, 7397−7402.

(6) (a) Zibinsky, M.; Fokin, V. V. Sulfonyl-1,2,3-Triazoles: Convenient Synthones for Heterocyclic Compounds. *Angew. Chem., Int. Ed.* **2013**, *52*, 1507−1510. (b) Miura, T.; Tanaka, T.; Hiraga, K.; Stewart, S. G.; Murakami, M. Stereoselective Synthesis of 2,3-Dihydropyrroles from Terminal Alkynes, Azides, and α,β-Unsaturated Aldehydes via *N*-Sulfonyl-1,2,3-Triazoles. *J. Am. Chem. Soc.* **2013**, *135*, 13652−13655.

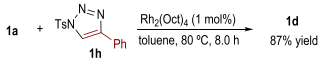
(7) (a) Shu, D.; Song, W.; Li, X.; Tang, W. Rhodium- and Platinum-Catalyzed [4 + 3] Cycloaddition with Concomitant Indole Annulation: Synthesis of Cyclohepta[*b*]indoles. *Angew. Chem., Int. Ed.* **2013**, *52*, 3237−3240. (b) Kim, S.; Mo, J.; Kim, J.; Ryu, T.; Lee, P. H. Aza-[4 + 3] and Aza-[3 + 2] Annulations for Synthesis of Dihydroazepines and Dihydropyrroles from Alkynes, Sulfonyl Azides, and 1,3-Dienes. *Asian J. Org. Chem.* **2014**, *3*, 926−931. (c) Schultz, E. E.; Lindsay, V. N. G.; Sarpong, R. Expedient Synthesis of Fused Azepine Derivatives Using a Sequential Rhodium(II)-Catalyzed Cyclopropanation/1-Aza-Cope Rearrangement of Dienyltriazoles. *Angew. Chem., Int. Ed.* **2014**, *53*, 9904−9908. (d) Tian, Y.; Wang, Y.; Shang, H.; Xu, X.; Tang, Y. Rhodium(ii)-catalyzed intramolecular formal [4 + 3] cycloadditions of dienyltriazoles: rapid access to fused 2,5-dihydroazepines. *Org. Biomol. Chem.* **2015**, *13*, 612−619.

(8) (a) Rostovtsev, V. V.; Green, L. G.; Fokin, V. V.; Sharpless, K. B. A Stepwise Huisgen Cycloaddition Process: Copper(I)-Catalyzed Regioselective "Ligation" of Azides and Terminal Alkynes. *Angew. Chem., Int. Ed.* **2002**, *41*, 2596−2599. (b) Tornøe, C.; Christensen, C.; Meldal, M. Peptidotriazoles on Solid Phase: [1,2,3]-Triazoles by Regiospecific Copper(I)-Catalyzed 1,3-Dipolar Cycloadditions of Terminal Alkynes to Azides. *J. Org. Chem.* **2002**, *67*, 3057−3064. (c) Yoo, E. J.; Ahlquist, M.; Kim, S. H.; Bae, I.; Fokin, V. V.; Sharpless, K. B.; Chang, S. Copper-Catalyzed Synthesis of *N*-Sulfonyl-1,2,3-triazoles: Controlling Selectivity. *Angew. Chem., Int. Ed.* **2007**, *46*, 1730−1733. (d) Raushel, J.; Fokin, V. V. Efficient Synthesis of 1-Sulfonyl-1,2,3-triazoles. *Org. Lett.* **2010**, *12*, 4952−4955. (e) Zhu, L.; Brassard, C. J.; Zhang, X.; Guha, P. M.; Clark, R. J. On the Mechanism of Copper(I)-Catalyzed Azide−Alkyne Cycloaddition. *Chem. Rec.* **2016**, *16*, 1501−1517.

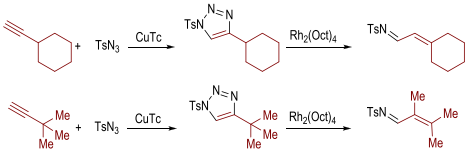
(9) (a) Chattopadhyay, B.; Gevorgyan, V. Transition-Metal-Catalyzed Denitrogenative Transannulation: Converting Triazoles into Other Heterocyclic Systems. *Angew. Chem., Int. Ed.* **2012**, *51*, 862−872. (b) Gulevich, A. V.; Gevorgyan, V. Versatile Reactivity of Rhodium-Iminocarbenes Derived from N-Sulfonyl Triazoles. *Angew. Chem., Int. Ed.* **2013**, *52*, 1371−1373. (c) Li, Y.; Yang, H.; Zhai, H. *Chem. - Eur. J.* **2018**, *24*, 12757−12766.

(10) (a) Woodward, R. B.; Hoffmann, R. Stereochemistry of Electrocyclic Reactions. *J. Am. Chem. Soc.* **1965**, *87*, 395−397. (b) Woodward, R. B.; Hoffmann, R. The Conservation of Orbital Symmetry. *Angew. Chem., Int. Ed. Engl.* **1969**, *8*, 781−932.

(11) Synthesis of azepine **1d** with enal **1a** and 1,2,3-triazole **1h** under a Rh catalyst.



(12) The 1,2-alkyl migration of C4-alkyl-substituted *N*-sulfonyl-1,2,3-triazols was reported by V. V. Fokin, see: Selander, N.; Worrell, B. T.; Fokin, V. V. *Angew. Chem., Int. Ed.* **2012**, *51*, 13054−13057.



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