Thermally Accessed Carbenes and Benzynes Derived from Alkynes as a Platform for Synthetic Methodology Development

Thesis by

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Acknowledgements

I have always been observant of the world around me and interested in how it works. Whether an innate attribute of mine or instilled in me through formative childhood experiences, such as Boy Scout camping adventures or noting changes in the passing of Minnesota seasons, this curiosity has been a persistent source of inspiration and guidance in my life. During my high school years at the Breck School, family members and mentors showed me how I could translate my curiosities and creative enterprise into mission-driven, real-world change. Tim Rosenfield, my freshman-year history teacher, was particularly instrumental in my academic development. He inspired me to ask big questions. Through his influence, I adopted a love for language in both the educational and creative spheres. While I enjoyed exposure to the liberal arts curriculum, I was becoming increasingly aware and concerned over the consequences of climate change and the misuse of natural/environmental resources.

Although my environmental awareness grew out of my educational background, my belief that I could do something about it was fostered by my grandfather, Alberto Guzman. Over the period of a late-afternoon lunch, he convinced me that scientific innovation was an immensely power tool in shaping a sustainable future and that my education was a foundation for enacting meaningful change. I had reasons to trust in his call to action. Scientific occupations have been an essential part of my family history. In 1967, my grandfather accepted an engineering research position at Carnegie Mellon University, uprooted his life in Argentina, and moved, along with my grandmother, aunt, and father, to Pittsburgh. My father, Javier Guzman, continued this occupational legacy, working for Seagate (based in the Twin Cities metro area) as an engineer.

My decision to pursue a career in chemistry directly stemmed from this innovation-driven sustainability ethos. During the first several weeks of college at the University of Puget Sound, I attended a talk on sustainable organic chemistry presented by Professor Luc Boisvert. His lecture motivated my undergraduate studies in chemistry by illustrating how investigation of the molecular world can provide a powerful framework for solving challenges in sustainability. While taking Professor Boisvert's organic chemistry course, my appreciation for the field grew beyond a "means to an end" perspective. I recognized the art of organic chemistry in how molecules are depicted through various models and constructed using logical, yet creative, synthetic puzzles. My formative undergraduate years at the University of Puget Sound were made possible by the

generous financial support of Gwen and Chuck Lillis, and I am honored to have been selected as a Lillis Scholar.

In preparation for graduate school, I participated in a summer REU experience at the University of Utah under the mentorship of Professor Andrew Roberts and my graduate student mentor, Dallas Keyes. During those months, I was exposed to a graduate-level research environment and knowledge base. Professor Andrew Roberts helped me to equilibrate to this new setting and buffered elevated expectations with supportive mentorship and one-on-one lectures or consultations.

In 2020, I was primed and ready to start my graduate studies at the University of Minnesota; however, I could have never prepared for or predicted the events that transpired throughout the COVID-19 pandemic. Thankfully, I had endless support from my family – my mother (Colleen), father (Javier), and two brothers (Luis and Elliott). To Austin, Jake, Joe, Henry, and Carla, your friendships have provided me the deepest sense of inspiration, belonging, and purpose.

Throughout my graduate studies, mentors, collaborators, and friends in the Hoye lab were crucial to my development as a scientist. Therefore, I want to thank Daniel Lee, Dorian Sneddon, Casey Ritts, Niklas Kraemer, Paul Kevorkian, Katharine Toll, and Alexis Mann. I would like to give a special acknowledgement to my friend Paul Kevorkian, who I've spent countless hours with side-by-side and hood-by-hood – working, laughing, and supporting each other through the journey of graduate school.

I am grateful for Chris Douglas taking me on as an MPACT mentee and teaching me about lecture preparation, pedagogical methods, and project-centered course development.

Lastly, I want to thank my advisor, Tom Hoye. He has been far more than just a teacher or conveyor of his seemingly endless pool of chemistry knowledge. His research ethos and curiosity-driven innovation philosophy have been major sources of inspiration throughout my graduate studies. Under his guidance and instruction, I have greatly improved my scientific communication, whether that be in the form of writing, figures, or oral presentation. I have much to thank for his mentorship as I begin my post-graduate career as a process chemist.

Abstract

^{1}H NMR (proton nuclear magnetic resonance) spectroscopy is the most widely used tool for the identification and characterization of organic compounds. Accurate referencing of ^{1}H NMR data is particularly important for comparison of spectra of different samples of the same substance. In my first research project, I compared the effectiveness, and therefore accuracy, of the most common ^{1}H NMR reference compound, tetramethylsilane (TMS). My findings explicitly show that TMS is a superior reference compound compared to the residual $CHCl_3$ that is often referenced when using $CDCl_3$ solutions (Chapter 1).

The hexadehydro-Diels–Alder (HDDA) reaction is the thermal or photochemical cycloisomerization of a poly-yne system to produce an *o*-benzyne intermediate. The fleeting *o*-benzyne is trapped in situ to afford benzenoid products. Given the paramount importance of heterocycles in modern drug discovery efforts, there has been a growing impetus to incorporate heterocycles into the framework of HDDA chemistry. From this perspective, I was curious to study the reactivity of oxadiazoles with HDDA benzynes, and consequently I discovered novel oxadiazole reactivity, producing a series of 2:1 adducts (Chapter 2).

Alkynes may also be used as precursors for the generation of free carbenes, another type of high-energy, fleeting intermediate. Few examples of alkyne-derived free carbene generation have been reported. However, in 2024, Xu and Hoye demonstrated the broad synthetic utility of heteroaryl free carbenes, produced by the formal (3+2) cycloaddition between 2-alkynyl iminoheterocycles and electron-deficient alkynes. I expanded upon this work, showcasing how this 100% atom economical carbene methodology could be applied to the synthesis of complex, polycyclic cyclopropanes (Chapter 3). During the cyclopropanation study, I unexpectedly isolated a product arising from an intermolecular formal C–H insertion into a terminal alkyne. In recognizing that intermolecular trapping of free carbenes could be broadly applied to a host of trapping functionalities, I capitalized on this idea and developed a three-component coupling methodology in which free carbenes can be trapped by terminal alkynes, *N*-Boc carbamates, and amides (Chapter 4).

Table of Contents

List of Tables

List of Figures

List of Abbreviations

Ar	Aryl
amu	Atomic mass unit
Bn	Benzyl
Boc	*tert*-Butoxycarbonyl
DA	Diels–Alder
DBU	1,8-Diazabicyclo[5.4.0]-undec-7-ene
DCE	Dichloroethane
DCM	Methylene chloride
DDDA	Didehydro-Diels–Alder
DFT	Density functional theory
DMAD	Dimethyl acetylenedicarboxylate
DMF	Dimethylformamide
DMI	Dimethyl iso-phthalate
DMSO	Dimethyl sulfoxide
DOSP	(Dodecylbenzenesulfonyl)prolinate
EDG	Electron donating group
Et	Ethyl
Et_2O	Diethyl ether
EtOAc	Ethyl acetate
EtOH	Ethyl alcohol
$(EtO)_3PO$	Triethyl phosphate
EWG	Electron withdrawing group
Fmoc	Fluorenylmethoxycarbonyl
FOM	Figure of merit
HDDA	Hexadehydro-Diels–Alder
het	Heterocycle
HFB	Hexafluorobenzene
HMBC	Heteronuclear multiple bond correlation
HMPA	Hexamethylphosphoramide
HOMO	Highest occupied molecular orbital
HSQC	Heteronuclear single quantum coherence
IR	Infrared
IUPAC	International Union of Pure and Applied Chemistry
LUMO	Lowest unoccupied molecular orbital
Me	Methyl

MeCN	Acetonitrile
Me_2CO	Acetone
MeOH	Methanol
Naph	Naphthyl
$^{n}BuNH_2$	*n*-Butylamine
^{n}BuLi	*n*-Butyllithium
^{n}hex	^{n}Hexyl
NHC	*N*-Heterocyclic carbene
NMR	Nuclear magnetic resonance
NOESY	Nuclear Overhauser effect spectroscopy
OTf	Trifluoromethanesulfonate
PBP	*p*-Bromophenyl
PES	Potential energy surface
Ph	Phenyl
PhH	Benzene
PMP	*p*-Methoxyphenyl
ppm	Parts per million
py	Pyridine
S_NAr	Nucleophilic aromatic substitution
TBAF	Tetrabutylammonium fluoride
TBS	Tertbutyldimethylsilyl
TEA	Triethylamine
TFA	Trifluoroacetic acid
TFT	Trifluorotoluene
THF	Tetrahydrofuran
TLC	Thin-layer chromatography
TMS	Tetramethylsilane or trimethylsilyl
TPPO	Triphenylphosphine oxide
UV	Ultraviolet
Val	Valine

Chapter I: TMS is Superior to Residual C*H*Cl_3 for Use as the Internal Reference for Routine ^{1}H NMR Spectra Recorded in $CDCl_3$

The following chapter reflects work that was published in the Journal of Organic Chemistry.

Guzman, A. L.; Hoye, T. R. TMS is superior to residual C*H*Cl_3 for use as the internal reference for routine ^{1}H NMR spectra recorded in $CDCl_3$. *J. Org. Chem.* **2022**, *87*, 905–909.

1.1 Introduction

Accurate referencing of the chemical shifts in NMR spectra provides an important means for judging whether different samples do (or do not) contain the same analyte. For proton NMR spectra, the tetramethylsilane (TMS) resonance is often used as an internal reference standard, as first proposed in 1958 by George Tiers of the 3M Company.[1] That suggestion, later endorsed by recommendation of the IUPAC,[2] was made based on i) the assumption that TMS would be relatively non-interactive with other solute molecules (e.g., it has no permanent dipole) and ii) the conveniently non-interfering upfield chemical shift of its methyl protons. The majority of ^{1}H NMR spectra are recorded and reported as solutions in $CDCl_3$. However, it is a common practice to reference the chemical shifts of the solute under study to the shift of the residual proton resonance of $CHCl_3$ (i.e., $\delta = 7.26$[3] ppm) rather than that of added TMS. Although this is an acceptable and sufficient approach for situations in which knowledge of the true chemical shifts of the solute is not critical, it is impossible to anticipate the situations in which future researchers might benefit from having a more accurate set of chemical shifts. The purpose of this focused study is to make the case for routine use of the TMS resonance ($\delta = 0.00$ ppm) rather than $CHCl_3$, an extremely easy practice to implement.

We have often observed some non-trivial changes in the chemical shift difference between residual $CHCl_3$ and TMS (i.e., $\delta_{CHCl3} - \delta_{TMS}$) for certain analytes. That change is concentration dependent for the same analyte. Most often the $\Delta\delta$ is >7.26 ppm, meaning that either one, the other, or both of the chemical shifts of $CHCl_3$ and TMS have been altered by the presence of the solute.

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[1] Tiers, G. V. D. Reliable proton nuclear resonance shielding values by "internal referencing" with tetramethyl-silane. *J. Phys. Chem.* **1958**, *62*, 1151–1152.

[2] Harris, R.; Becker, E. D.; Cabral De Menezes, S. M.; Goodfellow, R.; Granger, P. NMR nomenclature. Nuclear spin properties and conventions for chemical shifts. *Pure Appl. Chem.* **2001**, *73*, 1795–1818.

[3] Fulmer, G. R.; Miller, A. J. M.; Sherden, N. H.; Gottlieb, H. E.; Nudelman, A.; Stoltz, B. N.; Bercaw, J. E.; Goldberg, K. I. NMR chemical shifts of trace impurities: Common laboratory solvents, organics, and gases in deuterated solvents relevant to the organometallic chemist. *Organometallics* **2010**, *29*, 2176–2179.

The effect of added solute molecules on the chemical shift of $CHCl_3$ alone[4] or on TMS alone[5] have been previously studied, but to our knowledge the work here is the first study in which both have been parsed by simultaneous measurement. It is intuitive that $CHCl_3$ is more likely to interact with solute molecules because it possesses a permanent dipole and is a hydrogen bond donor. Hence, we have always assumed that the shift of the chloroform protons was being perturbed in these situations much more than (exclusively?) that of the TMS protons. Is that the case?

1.2 Results and Discussion

We addressed the preceding question through experiments in which a portion of $CDCl_3$ (99.8% D) containing 0.05% TMS but no added solute was compared in a head-to-head fashion with solutions of various solutes in that same NMR solvent. We used a concentric tube arrangement similar to that shown in Figure 1 to achieve a simultaneous measurement of these two, compartmentalized solutions.[6] The solutes examined are shown in Table 1; each was a small molecule containing a single functional group representing, collectively, the majority of functionalities present in a wide array of organic molecules. The internal capillary portion always contained the same solution of $CDCl_3$/TMS, which we call here the "standard." Using serial dilution, we varied the concentration of solute across a wide range ($\leq$8 M to $\geq$16 mM). The lowest of these corresponds to a sample size of ca. 4 mg of a solute with a molecular weight of 400 amu in an NMR sample volume of ca. 700 μL.

[4] Kaiser, R. Solvent shift of the chloroform nuclear magnetic resonance line. *Can. J. Chem.* **1963**, *41*, 430–439.
[5] Laszlo, P.; Speert, A. Reconsidering of the internal tetramethylsilane reference for proton magnetic resonance studies. *J. Chem. Phys.* **1968**, *48*, 1732–1735.
[6] Homer J.; Hartland, E. J.; Jackson, C. J. Molecular complexes. Part VI. A new procedure for investigating molecular integrations in solution by nuclear magnetic resonance spectroscopy. *J. Chem. Soc. A* **1970**, 931–935.

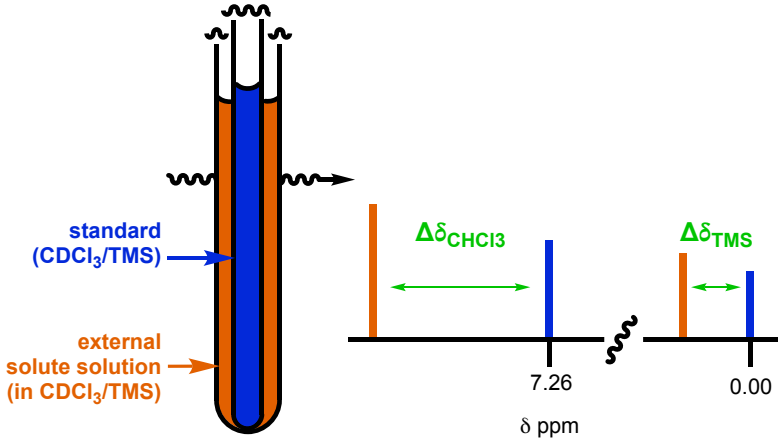

Figure 1. Schematic of the concentric tube arrangement in which the relative chemical shift changes of $CHCl_3$ and TMS induced by the presence of a solute could be simultaneously observed.

Table 1. Solutes Examined, Abbreviation, Functional Group, and Molecular Dipole

Solute	Abbreviation	Functional Group	Dipole
1,8-diazabicyclo[5.4.0]-undec-7-ene	DBU	amidine	3.41[7]
1-fluoronitrobenzene	-	alkyne	2.87[8]
1-pentyne	-	alkyne	0.85[9]
acetone	Me_2CO	ketone	2.9[10]
acetonitrile	MeCN	nitrile	3.2[10]
benzene	PhH	aromatic	0[10]
n-butylamine	$^nBuNH_2$	primary amine	1.00[8]
diethyl ether	Et_2O	ether	1.3[10]
dimethyl sulfoxide	DMSO	sulfoxide	3.96[10]
dimethyl iso-phthalate	DMI	aromatic	2.23[8]

[7] Hermecz, I. Chemistry of Diazabicycloundecene (DBU) and Other Pyrimidoazepines; In Katritzky, A. R. Ed. Advances in Heterocyclic Chemistry; Vol. 42. Academic Press Inc., **1987**; pp 84–169.
[8] Taken from Tables for Organic Chemistry: Dipole moments. www.stenutz.eu/chem/solv28.php (accessed 10/19/21).
[9] Taken from Computational Chemistry Comparison and Benchmark DataBase Release 21 (August 2020) Standard Reference Database 101 National Institute of Standards and Technology. https://cccbdb.nist.gov/diplistx.asp#NSRDS-NBS10 (accessed 10/18/21).
[10] Smallwood, I. M. Handbook of Organic Solvent Properties; John Wiley & Sons Inc., **1996**.

dimethylformamide	DMF	tertiary amide	3.8[10]
ethyl acetate	EtOAc	ester	1.78[9]
hexafluorobenzene	HFB	aromatic	0[8]
hexamethylphosphoramide	HMPA	phosphoramide	5.54[8]
methanol	MeOH	alcohol	1.7[10]
methylene chloride	DCM	chlorocarbon	1.8[10]
pyridine	py	heteroaromatic	2.3[10]
quinuclidine	-	amine	1.20[8]
tetrahydrofuran	THF	ether	1.75[10]
triethylamine	TEA	tertiary amine	0.66[9]
triethyl phosphate	$(EtO)_3PO$	phosphate ester	2.86[8]
trifluoroacetic acid	TFA	carboxylic acid	2.26[8]
triphenylphosphine oxide	TPPO	phosphine oxide	4.4[8]

Shown in Figure 2 is a representative subset of spectra for one of the solutes, arbitrarily acetone. There it is easy to visualize that the chemical shifts of TMS and $CHCl_3$ resonances in the standard (i.e., inner capillary) are invariant (as is the resonance for trace water). It is also obvious that the chloroform resonance is shifted to a greater extent than that of TMS as the concentration of acetone increases. However, the change in TMS chemical shift, albeit smaller, also demonstrates that TMS is not non-interacting (i.e., not inert). Nonetheless and as presented below, for nearly every solute examined, the effect on $CHCl_3$ was greater than that on TMS.

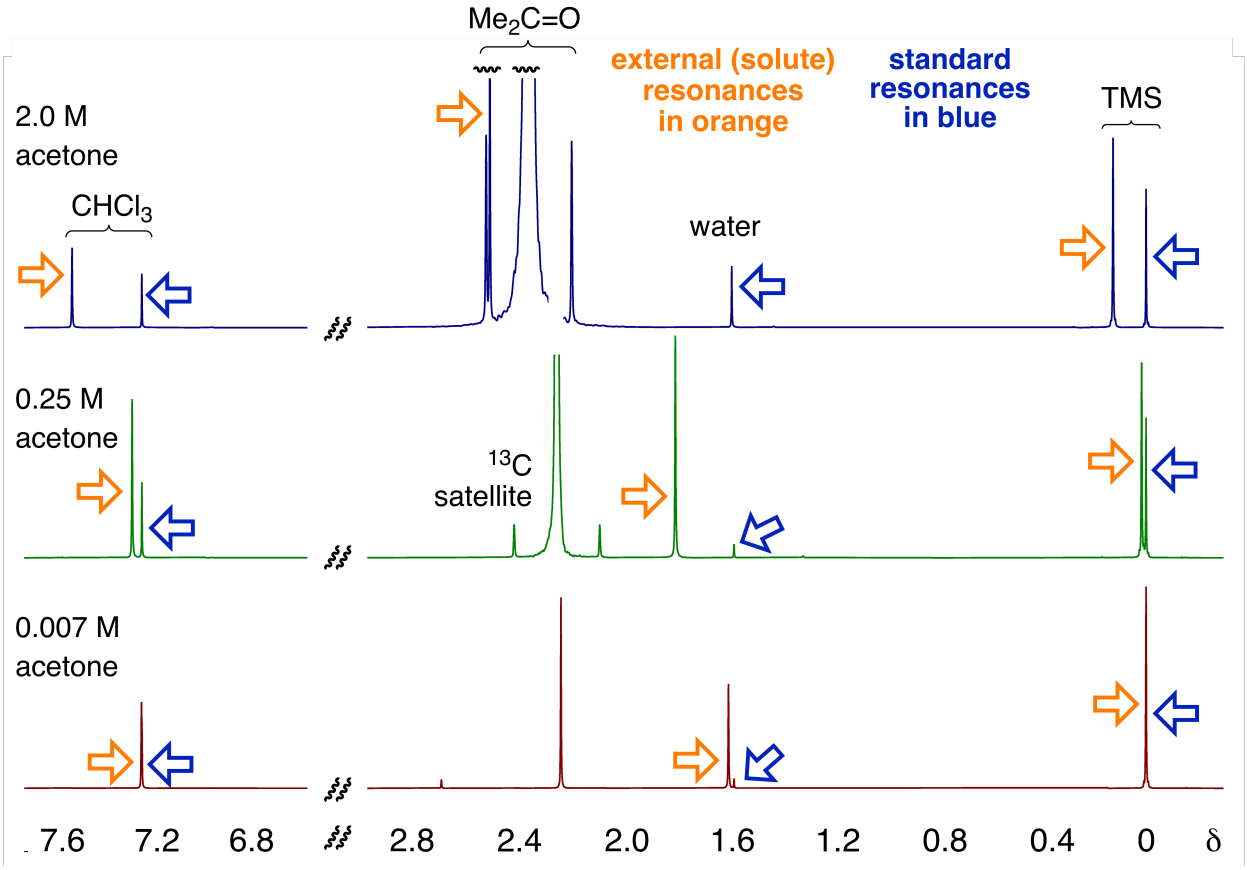

Figure 2. Spectra of various concentrations of acetone in $CDCl_3$ (99.8% deuteration) containing 0.05% TMS. Note: the relative intensities of the TMS to water resonances in the standard differ in the top vs. the bottom two spectra because a different bottle of $CDCl_3$/TMS was used.

Results from a typical full data set, this for CH_3OH, are shown graphically in Figure 3. Methanol happens to be a relatively weakly interacting solute. The good linearity (viz. R^2) of chemical shift differences across the full range of concentrations is easily seen, as is the similarity of the slopes across the full vs. the low-end range of concentrations (see inset). A single "figure of merit" (hereafter, "FOM") that captures the relative sensitivity (or response) of $CHCl_3$ vs. TMS is the ratio of the slopes for $CHCl_3$ vs. TMS over the full concentration range. This is shown for each solute in columns 4 and 6 in Table 2, discussed further below. The reproducibility of the data using the serial dilution methodology was checked by measuring the shift changes for one of the solutes, arbitrarily benzene, in triplicate, using newly prepared samples for each independent set of measurements. The relative standard deviation of the three slope values for each of the two chemical shifts is ca. 6%. This is perfectly adequate for drawing the overall conclusion that TMS is a more nearly inert substance than is chloroform.

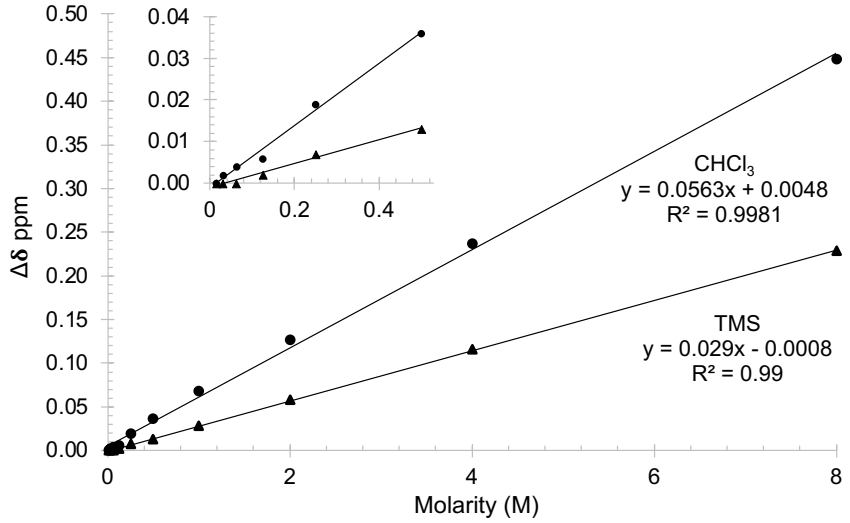

Figure 3. Chemical shift changes of $CHCl_3$ ($\Delta\delta_{CHCl3}$) vs. TMS ($\Delta\delta_{TMS}$) resonances as a function of CH_3OH (solute) concentration.

In Table 2 we have summarized the overall body of results. Columns 1–4 show the solutes (column 1) ordered according to their largest to smallest chemical shift effect on $CHCl_3$ (column 2). Column 3 contains the solute-induced chemical shift changes for TMS. Column 4 shows the FOM for each solute – i.e., the ratio of the chemical shift impact on $CHCl_3$ vs. TMS: |slope of $\Delta\delta_{CHCl3}$| ÷ |slope of $\Delta\delta_{TMS}$|. The data in columns 5 and 6 of Table 2 are listed in descending order of the magnitude of the FOMs for the solutes.

Perhaps not surprisingly, $CHCl_3$ experiences the largest chemical shift deviations in the presence of functional groups that are good hydrogen bond acceptors.[11] Benzene, hexafluorobenzene, and TPPO are the only solutes examined that induced a net shielding effect on chloroform's proton. In the case of complexes of benzenoid compounds with chloroform, shielding has been attributed to CH-π interactions that position the chloroform proton in the anisotropic shielding region of the aromatic electron density.[12] In the TPPO $CHCl_3$ complex, apparently the anisotropic shielding of the phenyls in TPPO outweighs the deshielding induced by the $Cl_3C–H---O=PPh_3$ hydrogen bond.

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[11] (a) Gordy, W. Spectroscopic evidence of hydrogen bonds: chloroform and bromoform in donor solvents. *J. Chem. Phys.* **1939**, *7*, 163–166. (b) Kwak, K.; Rosenfeld, D. E.; Chung, J. K.; Fayer, M. D. Solute-solvent complex switching dynamics of chloroform between acetone and dimethylsulfoxide-two-dimensional IR chemical exchange spectroscopy. *J. Phys. Chem. B* **2008**, *112*, 13906–13915.

[12] Reeves, L. W.; Schneider, W. G. Nuclear magnetic resonance measurements of complexes of chloroform with aromatic molecules and olefins. *Can. J. Chem.* **1957**, *35*, 251–261.

Table 2. Slope Values of the Change in the ^{1}H Chemical Shift vs. Solute Concentration for Chloroform (col 2) and for Tetramethylsilane (col 3) and the Ratio of those Two Slopes [the Figure of Merit (FOM)] as the Indicator of the Relative Sensitivity of $CHCl_3$ vs. TMS to the Presence of Solute (cols 4 and 6)

solutes ordered according to the magnitude of their shift perturbations on $CHCl_3$				solutes ordered according to their relative shift perturbations on $CHCl_3$ vs. TMS	
1	2	3	4	5	6
solute	**slope of $\Delta\delta$ $CHCl_3$ (ppm/M)**	**slope of $\Delta\delta$ TMS (ppm/M)**	**FOM |slope of $\Delta\delta_{CHCl3}$| / |slope of $\Delta\delta_{TMS}$|**	**solute**	**FOM |slope of $\Delta\delta_{CHCl3}$| / |slope of $\Delta\delta_{TMS}$|**
HMPA	0.356	0.019	18.45	pyridine	>100
DBU	0.315	0.017	18.83	DBU	18.83
$(EtO)_3P=O$	0.232	0.045	5.16	HMPA	18.45
TEA	0.205	0.058	3.52	benzene	7.11
n-$BuNH_2$	0.200	0.046	4.32	quinuclidine	6.52
DMSO	0.169	0.030	5.69	DMSO	5.69
DMF	0.154	0.039	3.91	$(EtO)_3P=O$	5.16
acetone	0.142	0.072	1.98	n-$BuNH_2$	4.32
ether	0.134	0.070	1.93	DMF	3.91
pyridine	0.118	[a]	>100	TEA	3.52
EtOAc	0.116	0.055	2.10	THF	3.42
quinuclidine	0.099	0.015	6.52	EtOAc	2.10
THF	0.083	0.024	3.42	acetone	1.98
1-pentyne	0.080	0.062	1.30	MeOH	1.95
MeCN	0.069	0.042	1.63	ether	1.93
MeOH	0.056	0.029	1.95	MeCN	1.63
TFA	0.043	0.043	1.02	1-pentyne	1.30
DMI	0.038	-0.029	1.29	DMI	1.29
4-fluoronitrobenzene	0.010	-0.011	0.96	TFA	1.02
DCM	0.002	-0.002	1.00	DCM	1.00
benzene	-0.107 ± 0.006	0.015 ± 0.0003	7.11	4-fluoronitrobenzene	0.96
TPPO	-0.024	-0.101	0.24	hexafluorobenzene	0.72
hexafluorobenzene	-0.017	-0.023	0.72	TPPO	0.24

[a] $\Delta\delta_{TMS} < 0.01$ ppm even at 8 M.

The nature of the interactions between TMS and the solutes at the molecular level is likely more highly variable for different solutes[5,13] than is the case for the complexes between solutes and $CHCl_3$. The general trend we observed for TMS is that most solutes induce a downfield, but small, shift in the methyl proton resonances. As a side note, we should mention that $CDCl_3$ is notorious

[13] (a) Homer J.; Hartland, E. J.; Jackson, C. J. Molecular Complexes. Part VI. A new procedure for investigating molecular interactions in solution by nuclear magnetic resonance spectroscopy. *J. Chem. Soc. A* **1970**, 931–935. (b) Bacon, M. R.; Maciel, G. E. Solvent effects on the five shielding constants in tetramethylsilane and cyclohexane. *J. Am. Chem. Soc.* **1973**, *95*, 2413–2426.

for producing and, therefore, containing small amounts of HCl over time. This arises from slow autoxidation to produce phosgene followed by hydrolysis with adventitious water. This perhaps most often has come to light in studies involving low concentrations of basic nitrogenous compounds (e.g., alkaloid natural products).[14]

It is not obvious that the FOMs correlate with any single, simple parameter associated with each of the solutes. For example, we wondered whether the molecular dipole of the solute (cf. Table 1) might map onto the observed trends in FOMs. However, such a correlation is weak at best (see Supporting Information for linear regression plots showing an R^2 of merely 0.01 for FOM vs. dipole moment and 0.21 for the slope of $\Delta\delta_{CHCl3}$ vs dipole moment).

For the great majority of solute functional groups examined, the chemical shift of chloroform was affected to a greater extent than that of TMS. Thus, we conclude that (and recommend) the routine use of TMS as the reference compound when collecting routine spectra in $CDCl_3$. For only TPPO, 4-fluoronitrobenzene, and hexafluorobenzene were the FOMs ≤1.0.

We note that several, more-sophisticated, first principle protocols for referencing spectra to the "absolute" chemical shift of TMS have been developed.[15] While these would be superior to what we are recommending here, none are trivial to implement and would be impractical for adoption on a routine basis.

We also note that there will always exist a (small) subset of instances in which it might be advisable to use a source of $CDCl_3$ that contains no TMS. For example, the interpretation of spectra of organosilane compounds can be convoluted by the presence of Me_4Si. However, there are several relatively straightforward ways of deducing which of an array of upfield singlets in a spectrum is the one due to Me_4Si. For example, the relative intensities of the $CHCl_3$ and TMS singlets will be relatively constant throughout the use of a bottle of TMS-doped $CDCl_3$. The Δδ of the two resonances will likely be ca. 7.26, especially for dilute solutions of the analyte. Finally, if at all in doubt, the sample can be doped with, say, an equal volume of additional NMR solvent,

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[14] Maltese, F.; van der Kooy, F.; Verpoorte, R. Solvent derived artifacts in natural products chemistry. *Nat. Prod. Commun.* **2009**, *4*, 447–454.

[15] (a) Hoffman, R. E. Variations on the chemical shift of TMS. *J. Magn. Reson.* **2003**, *163*, 325–331. (b) Harris, R. K.; Becker, E. D.; Cabral De Menezes, S. M.; Granger, P.; Hoffman, R. E.; Zilm, K. W. Further conventions for NMR shielding and chemical shifts (IUPAC recommendations 2008). *Pure Appl. Chem.* **2008**, *80*, 59–84 (and references therein).

after which only the TMS singlet will have increased in relative intensity to the other silylated CH resonances.

Finally, we wondered whether the trends observed for $CDCl_3$/TMS solutions would carry over to other commonly used NMR solvents. We briefly addressed that question by examining a 2 M solution of, arbitrarily, diethyl ether in acetone-d_6, benzene-d_6, DMSO-d_6, and methanol-d_4 using the concentric tube arrangement (see SI). The resonances for TMS and the residual solvent ^{1}H were perturbed to a very similar extent. Therefore, it appears that the use of TMS as the reference compound is not as critical for these (less frequently used) solvents as it is for $CDCl_3$.

1.3 Conclusion

It is true that in some cases having a more accurate set of chemical shifts may not ever matter (e.g., if no other researcher ever records the ^{1}H NMR spectrum of the same substance). But in some cases, the improvement afforded by the use of TMS as the reference compound is of value. For example, structurally complex natural products often are reisolated or synthesized (long) after the initial report of their isolation and structure determination. Because it is nearly impossible to know in advance when greater chemical shift accuracy will prove beneficial, why not be in the habit of always collecting more accurate data in the first place, especially since it is trivial to do so?

No internal reference compound will be truly inert, and we certainly are not purporting here that TMS is non-interacting. Nonetheless, referencing chemical shifts to TMS rather than residual $CHCl_3$ is a superior practice, especially given that it is so easy to implement for those not currently doing so.

Chapter II Background: The Hexadehydro-Diels–Alder Reaction

2.1 History & Early Reports of Arynes

Arynes are highly reactive intermediates which, upon trapping, lead to functionalized aromatic products.[16] Formally, an aryne is an intermediate that results from the elimination of two substituents from a parent aromatic compound.[17] Aryne chemistry has captivated chemists not only due to the unique physical properties of arynes, but also due to the synthetic utility of achieving efficient routes to natural products and polyaromatic compounds.[18] The realization that arynes can serve as synthetically useful intermediates has spurred a significant increase in aryne research during the past two decades.[16] Stoermer and Kahlert first postulated the existence of aryne intermediates[19a,b] in 1902 after observing 3-bromobenzofuran (**1**) reacting with a strong base (KOH) to afford ethoxy-substituted benzofuran **2** (Figure 4).[19c] The aryne intermediate **A** presumably formed from a dehydrohalogenation process, and it provided Stoermer and Kahlert a coherent explanation for the isolated product.

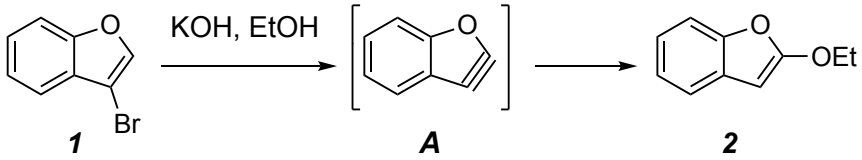

Figure 4. First proposed aryne generation: Stoermer & Kahlert 1902.

Although researchers evoked aryne intermediates during the decades that followed Stoermer and Kahlert's initial discovery, convincing evidence for the existence of aryne intermediates was not conveyed until Roberts and co-workers conducted a ^{14}C labeling study of chlorobenzene (**3**) in 1953 (Figure 5).[20] When ^{14}C labeled chlorobenzene (**3**) was subjected to KNH_2 in liquid ammonia conditions, Roberts observed a ~1:1 product distribution of aniline regioisomers **4a** and **4b**. The nearly equivalent product ratio implies that an S_NAr mechanism was

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[16] Shi, J.; Li, L.; Li, Y. *O*-silylaryl triflates: A journey of kobayashi aryne precursors. *Chem. Rev.* **2021**, *121*, 3892–4044.
[17] Wenk, H. H.; Winkler, M.; Sander, W. One century of aryne chemistry. *Angew. Chem. Int. Ed.* **2003**, *42*, 502–528.
[18] Takikawa, H.; Nishii, A.; Sakai, T.; Suzuki, K. Aryne-based strategy in the total synthesis of naturally occurring polycyclic compounds. *Chem. Soc. Rev.* **2018**, *47*, 8030–8056.
[19] (a) Reinecke, M. G. Hetarynes. *Tetrahedron* **1982**, *38*, 427−498. (b) Kauffmann, T. The Hetarynes. *Angew. Chem., Int. Ed. Engl.* **1965**, *4*, 543−557. (c) Stoermer, R.; Kahlert, B. Ueber das 1- und 2-Brom-cumaron. *Berichte Dtsch. Chem. Ges.* **1902**, *35*, 1633–1640.
[20] Roberts, J. D.; Simmons, H. E.; Carlsmith, L. A.; Vaughan, C. W. Rearrangement in the reaction of chlorobenzene-1-C^{14} with potassium amide. *J. Am. Chem. Soc.* **1953**, *75*, 3290–3291.

not occurring and that a symmetrical intermediate formed with equal probability of nucleophilic attack at either carbon atom. While Roberts' C^{14} experiment did not directly probe benzyne intermediates, it represented the first mechanistic study to disclose convincing evidence for the existence of benzynes. Direct spectroscopic detection of benzynes was achieved during the following two decades with Berry and co-workers' UV measurements (1962)[21] and Chapman and co-workers' IR experiments (1973).[22]

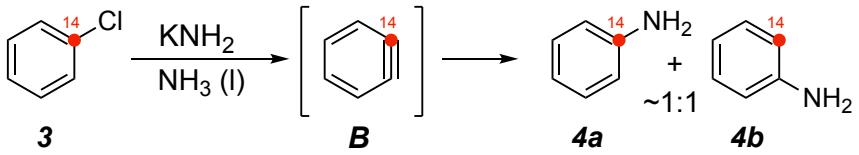

Figure 5. Roberts' ^{14}C mechanism study: first mechanistic evidence for the existence of benzynes.

2.2 The Nature and Reactivity of *o*-Benzynes

o-Benzynes may be represented as three resonance structures: one with an embedded cumulene structure (**i**), another containing a strained alkyne subunit (**ii**), and one diradical representation (**iii**) (Figure 6). Spectroscopic evidence, however, suggests that the more accurate representation of *o*-benzyne is the strained alkyne **ii**.[23] Microwave[24] and ultraviolet photoelectron spectroscopy[25] measurements have elucidated the structural parameters of benzynes and have shown that benzynes do not display diradical behavior.

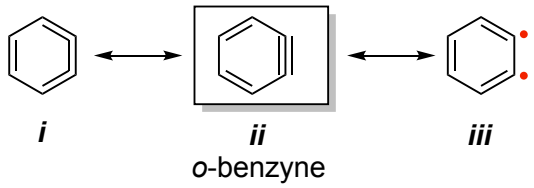

Figure 6. Major resonance contributors of *o*-benzyne: cumulene, alkyne, and diradical representations.

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[21] Berry, R. Stephen.; Spokes, G. Neil.; Stiles, Martin. The absorption spectrum of gaseous benzyne. *J. Am. Chem. Soc.* **1962**, *84*, 3570–3577.
[22] Chapman, O. L.; Mattes, K.; McIntosh, C. L.; Pacansky, J.; Calder, G. V.; Orr, G. Photochemical transformations. LII. benzyne. *J. Am. Chem. Soc.* **1973**, *95*, 6134–6135.
[23] Münzel, N.; Schweig, A. UV/VIS absorption spectrum, geometry and electronic structure of transient *o*-benzyne. *Chem. Phys. Lett.* **1988**, *147*, 192–194.
[24] Kukolich, S. G.; Tanjaroon, C.; McCarthy, M. C.; Thaddeus, P. Microwave spectrum of *o*-benzyne produced in a discharge nozzle. *J. Chem. Phys.* **2003**, *119*, 4353–4359.
[25] Wenthold, P. G.; Squires, R. R.; Lineberger, W. C. Ultraviolet photoelectron spectroscopy of the *o*-, *m*-, and *p*-benzyne negative ions. Electron affinities and singlet−triplet splittings for *o*-, *m*-, and *p*-benzyne. *J. Am. Chem. Soc.* **1998**, *120*, 5279–5290.

The π bond that resides orthogonal to a benzyne's aromatic *p* orbitals is responsible for the electrophilic reactivity of *o*-benzyne. Due to this orthogonal relationship, the aromatic π system does not interact with the reactive π bond and thus has no influence on benzyne reactivity. Rather, benzyne reactivity is primarily governed by the benzyne's sigma network that ordains its influence through geometric and inductive effects.[26] Substituted benzynes have inherent geometric distortions that cause compression of one C_{sp2}-C_{sp} bond angle (β) and flattening of the adjacent C_{sp}-C_{sp2} bond angle (α) (Figure 7).[27] According to the Aryne Distortion Model, distortions of the benzyne's sigma framework induces polarization of the benzyne's triple bond, leading to regioselective consequences.[27,28,29] The larger bond angle, α, renders the orthogonal *p* orbital more electron deficient and makes C_α more electrophilic.[28] Inductively active functionalities and bulky substituents neighboring the benzyne's electrophilic carbon centers may also influence the benzyne's reactivity and regiochemical outcomes.[27]

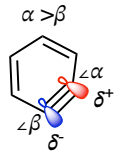

Figure 7. Effects of geometric distortions on the electronics of *o*-benzynes.

2.3 Benzyne Generation Methods

As exemplified by the work of Stoermer and Kahlert (see Figure 4), the earliest methods of generating benzynes relied on a dehydrohalogenation-elimination process. In the decades that followed the 1950's, a diverse and extensive catalogue of methods have been developed for benzyne generation. To date, benzyne generation methods include demetalhalogenation (**5**),[30]

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[26] Lewis, D.; *Advanced Organic Chemistry*, Oxford University Press, 2016.
[27] Medina, J. M.; Mackey, J. L.; Garg, N. K.; Houk, K. N. The role of aryne distortions, steric effects, and charges in regioselectivities of aryne reactions. *J. Am. Chem. Soc.* **2014**, *136*, 15798–15798.
[28] Im, G.-Y. J.; Bronner, S. M.; Goetz, A. E.; Paton, R. S.; Cheong, P. H.-Y.; Houk, K. N.; Garg, N. K. Indolyne experimental and computational studies: Synthetic applications and origins of selectivities of nucleophilic additions. *J. Am. Chem. Soc.* **2010**, *132*, 17933–17944.
[29] Garr, A. N.; Luo, D.; Brown, N.; Cramer, C. J.; Buszek, K. R.; VanderVelde, D. Experimental and theoretical investigations into the unusual regioselectivity of 4,5-, 5,6-, and 6,7-indole aryne cycloadditions. *Org. Lett.* **2010**, *12*, 96–99.
[30] Heaney, H.; Mann, G.; Millar, T. I. The Reaction of *o*-di-iodobenxene with magnesium, lithium, and *n*-butyl-lithium. *J. Chem. Soc.* **1956**, 1–5.

thermal decomposition of diphenyliodonium-2-carboxylates (**6**),[31] palladium-mediated decarboxylation (**7**),[32] elimination of *o*-trimethylsilyl phenyl triflates (**8**) (Kobayashi),[33] and the hexadehydro-Diels–Alder reaction (**9**) (Figure 5).[34]

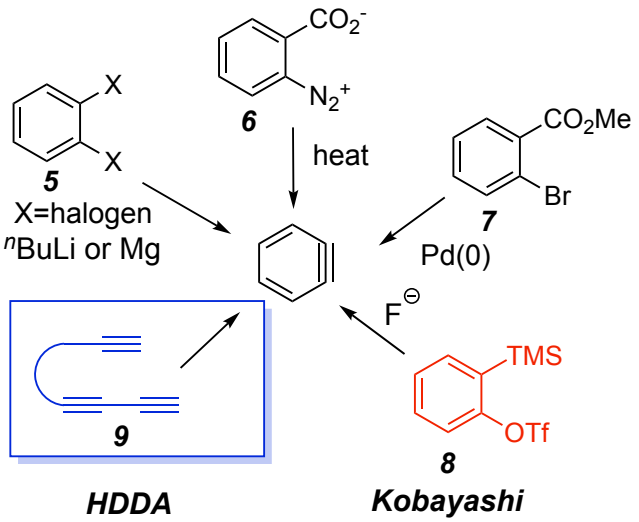

Figure 8. Selected methods for benzyne generation.

The prevailing method for generating benzynes is the Kobayashi method.[16] Kobayashi and co-workers demonstrated in 1983 that a 1,2-elimination event can be induced by reacting fluoride anion with *o*-trimethylsilyl phenyl triflates for the facile generation of benzynes under mild conditions.[33] Furthermore, the Kobayashi method has gained popularity because it ensures that only a low concentration of the benzyne intermediate is present in solution, which is commonly a desired control feature. This behavior is attributed to the low solubility of CsF (fluoride source) in standard Kobayashi reaction solvents.[35]

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[31] Le Goff, E. Aprotic generation of benzyne from diphenyliodonium-2-carboxylate. *J. Am. Chem. Soc.* **1962**, *84*, 3786–3786.
[32] Kim, H. S.; Gowrisankar, S.; Kim, E. S.; Kim, J. N. A Brand-new Pd-mediated generation of benzyne and its [2+2+2] cycloaddition: δ-Carbon elimination and concomitant decarboxylation. *Tetrahedron Lett.* **2008**, *49*, 6569–6572.
[33] Himeshima, Y.; Sonoda, T.; Kobayashi, H. Fluoride-induced 1,2-elimination of *o*-trimethylsilylphenyl triflate to benzyne under mild conditions. *Chem. Lett.* **1983**, *12*, 1211–1214.
[34] Hoye, T. R.; Baire, B.; Niu, D.; Willoughby, P. H.; Woods, B. P. The hexadehydro-Diels–Alder reaction. *Nature* **2012**, *490*, 208–212.
[35] Dubrovskiy, A. V.; Markina, N. A.; Larock, R. C. Use of benzynes for the synthesis of heterocycles. *Org. Biomol. Chem.* **2013**, *11*, 191–218.

2.4 HDDA Benzynes

The thermal or photochemical cycloisomerization between a diyne and diynophile to form an *o*-benzyne is known as the hexadehydro-Diels–Alder (HDDA) reaction. Similar to the classical Diels–Alder (DA) and didehydro-Diels–Alder (DDDA) reactions, the HDDA reaction is a formal [4+2] cycloaddition. However, the HDDA reaction represents the highest oxidation state variant in which six protons have formally been removed from traditional Diels–Alder substrates (Figure 9).

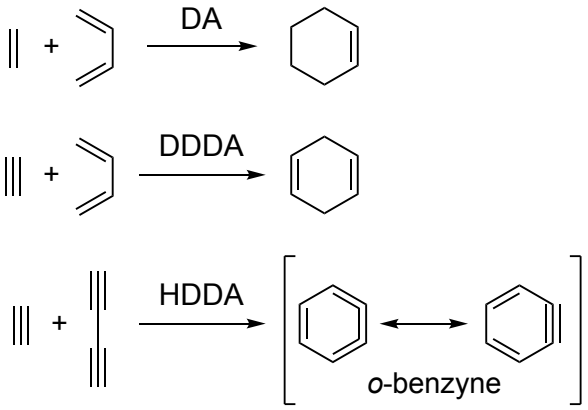

Figure 9. Selected Diel–Alder reactions, including "dehydro" variants.

Although the HDDA reaction was independently discovered by Ueda[36] and Johnson[37] in 1997 (Figure 10), the reactivity of HDDA benzynes remained mostly unexplored until Hoye and co-works published their seminal paper in 2012.[34] One of the greatest advantages attributed to HDDA chemistry is the ability to form benzynes in absence of initiators. As a result, HDDA generated benzynes have expressed divergent reactivity that has provided the opportunity to discover novel benzyne chemistry.[38]

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[36] Miyawaki, K.; Suzuki, R.; Kawano, T.; Ueda, I. Cycloaromatization of a non-conjugated polyenyne system: Synthesis of 5H-benzo[d]fluoreno[3,2-b]pyrans via diradicals generated from 1-[2-{4-(2-alkoxymethylphenyl)butan-1,3-diynyl}]phenylpentan-2,4-diyn-l-ols and trapping evidence for the 1,2-didehydrobenzene diradical. *Tetrahedron Lett.* **1997**, *38*, 3943–3946.
[37] Bradley, A. Z.; Johnson, R. P. Thermolysis of 1,3,8-nonatriyne: Evidence for intramolecular [2 + 4] cycloaromatization to a benzyne intermediate. *J. Am. Chem. Soc.* **1997**, *119*, 9917–9918.
[38] Ritts, C. B.; Hoye, T. R. Sulfurane [S(IV)]-mediated fusion of benzynes leads to helical dibenzofurans. *J. Am. Chem. Soc.* **2021**, *143*, 13501–13506.

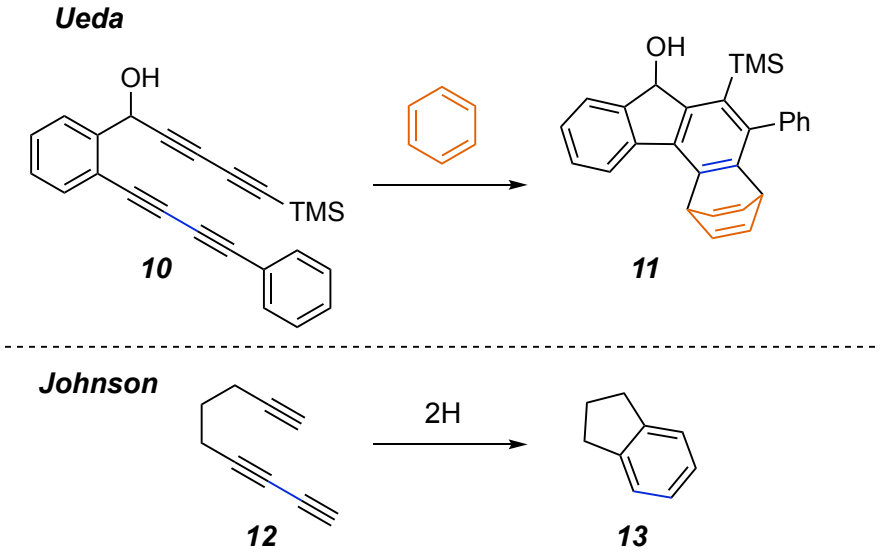


Figure 10. Ueda and Johnson's independent discoveries of the HDDA reaction.

Despite benzynes being high-energy intermediates, there is a strong thermodynamic driving force for generating HDDA benzynes. Density Functional Theory (DFT) computations show that a typical HDDA cycloisomerization is exothermic by ~51 kcal mol^{-1}.[34,39] Moreover, the concomitant trapping event is exothermic by an additional ~73 kcal mol^{-1}, which renders HDDA trapping cascades exothermic by >120 kcal mol^{-1}.

2.5 HDDA Mechanism

When Ueda initially discovered the thermal isomerization of tetrayne **10**, the product was accounted for by proposing a series of diradical intermediates illustrated in Figure 11.[36,40] It was postulated that an initial bond-forming step generates a C-C bond and two adjacent divalent radicals in intermediate **C**. A 6-*endo-dig* radical cyclization produces the benzyne **D**. In 2015, Marell and co-workers studied the HDDA mechanism through a computational lens, and their work suggests that HDDA thermal isomerizations are "highly asynchronous" and "stepwise-like".[41] Analysis of the computed thermodynamic surfaces showed that diradical intermediates may be stable for substrates that have radical stabilizing groups adjacent to the divalent radical

[39] Ajaz, A.; Bradley, A. Z.; Burrell, R. C.; Li, W. H. H.; Daoust, K. J.; Bovee, L. B.; DiRico, K. J.; Johnson, R. P. Concerted vs stepwise mechanisms in dehydro-Diels–Alder reactions. *J. Org. Chem.* **2011**, *76*, 9320–9328.
[40] Miyawaki, K.; Kawano, T.; Ueda, I. Domino thermal radical cycloaromatization of non-conjugated aromatic hexa- and heptaynes: Synthesis of fluoranthene and benzo[a]rubicene skeletons. *Tetrahedron Lett.* **2000**, *41*, 1447–1451.
[41] Marell, D. J.; Furan, L. R.; Woods, B. P.; Lei, X.; Bendelsmith, A. J.; Cramer, C. J.; Hoye, T. R.; Kuwata, K. T. Mechanism of the intramolecular hexadehydro-Diels–Alder reaction. *J. Org. Chem.* **2015**, *80*, 11744–11754.

centers. The following year, Wang and co-workers conducted an experimental study that tracked how radical stabilizing substituents influence reaction rate, and the experimental data strongly support a stepwise diradical mechanism.[42]

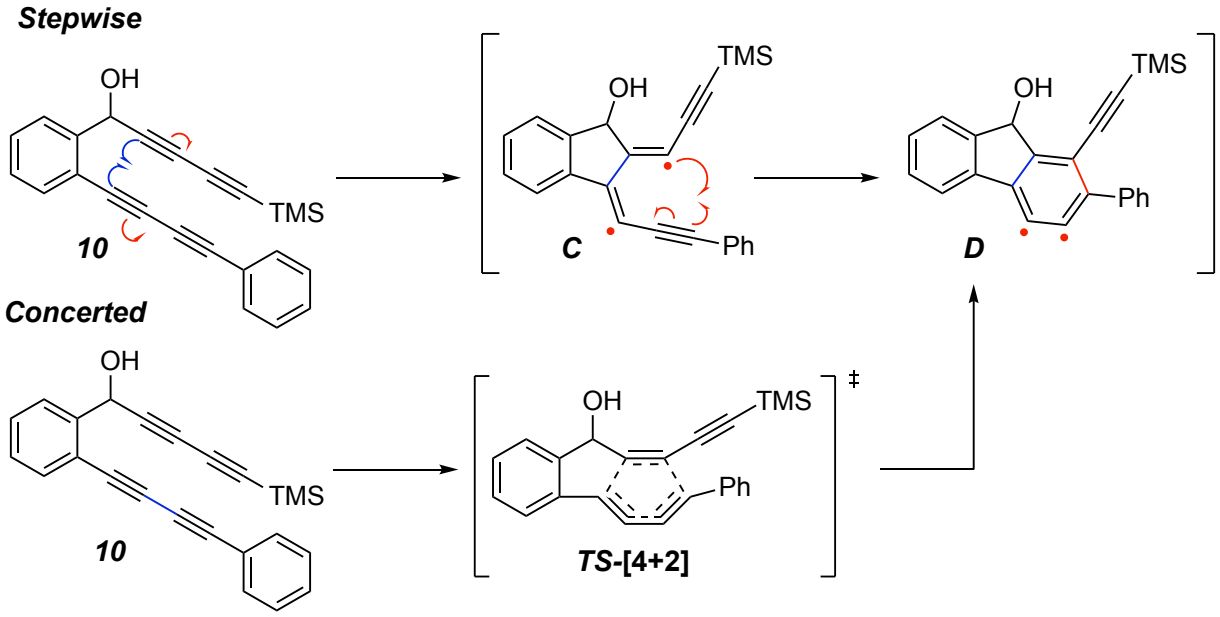


Figure 11. The stepwise diradical HDDA mechanism postulated by Ueda and the analogous concerted mechanism.

[42] Wang, T.; Niu, D.; Hoye, T. R. The hexadehydro-Diels–Alder cycloisomerization reaction proceeds by a stepwise mechanism. *J. Am. Chem. Soc.* **2016**, *138*, 7832–7835.

Chapter II: 2:1 Adducts Arising from Reactions between Benzynes and 1,3,4-Oxadiazoles

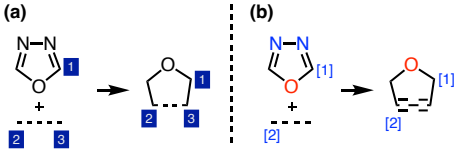
The following chapter reflects work that was published in Organic Letters with contributions made by Paul V. Kevorkian.

Guzman, A. L.; Kevorkian, P. V.; Hoye, T. R. 2:1 Adducts arising from reactions between benzynes and 1,3,4-oxadiazoles. *Org. Lett.* **2024**, *26*, 3834–3839.

2.6 Introduction

The cycloaddition chemistry of 1,3,4-oxadiazoles is well precedented.[43] The 1,3,4-oxadiazoles that participate in such reactions typically contain electron-withdrawing substituents (EWGs) in order to efficiently engage in inverse electron-demand [4+2] cycloadditions. For a subset of these cycloadditions, alkynes are the cycloaddends. In 1988 Sauer and co-workers demonstrated a cascade reaction between cyclooctyne (**14**) and 1,3,4-oxadiazoles **15** (Figure 12a) to produce 2:1 adducts **16**.[44] This is explained by an initial [4+2] cycloaddition to generate an oxadiazabicyclo[2.2.1]hepta-2,5-diene intermediate (cf. **E**) that expels dinitrogen to set up a final [4+2] cycloaddition of the furan derivative **F** with a second molecule of **14** to afford the oxabicyclic product **16**. That same year, Seitz and Wassmuth disclosed an analogous reaction of 2,5-bis(trifluoromethyl)-1,3,4-oxadiazole (**18**) with *o*-benzyne (**17**) to give **19** (Figure 12b).[45] 1,3,4-Oxadiazoles lacking EWGs have relatively higher LUMO orbitals and rarely participate in cycloaddition chemistry; other reaction pathways prevail.[46] For example, 2,5-dimethyl-1,3,4-oxadiazole (**20**) reacted with two equivalents of hexafluoro-2-butyne (**21**) to afford **22** (Figure

[43] The reaction search in (a) using SciFinder^n resulted in 116 citations to journal articles and patents for reactions involving C–C dienophiles. The reaction search in (b) ("substructures" on) using Reaxys resulted in 32 citations to journal articles and patents for single step reactions involving C–C dienophiles.



[44] Thalhammer, F.; Wallfahrer, U.; Sauer, J. 1,3,4-Oxadiazole als heterocyclische 4p-Komponenten in Diels–Alder–reaktionen. *Tetrahedron Lett*. **1988**, *29*, 3231–3234.
[45] Seitz, G.; Wassmuth H. 2,5-Bis(trifluormethyl)-1,3,4-oxadiazol und-tiadiazol als elektronenarme Diazadiene in der Diels-Alder-Reaktion mit inverse Elektronenbedarf. *Chemiker-Zeitung* **1988**, *112*, 80–81.
[46] Vasiliev, N. V.; Lyashenko, Y. E.; Patalakha, A. E.; Sokolski, G. A. Perfluoro-1,3,4-oxadiazoles. *J. Fluor. Chem.* **1993**, *65*, 227–231.

12c).[47] This reaction is believed to be initiated by nucleophilic attack of a nitrogen atom to the electrophilic alkyne carbon. Because benzynes are electrophilic alkynes, we were interested to examine more broadly the behavior of benzynes and various 1,3,4-oxadiazoles.

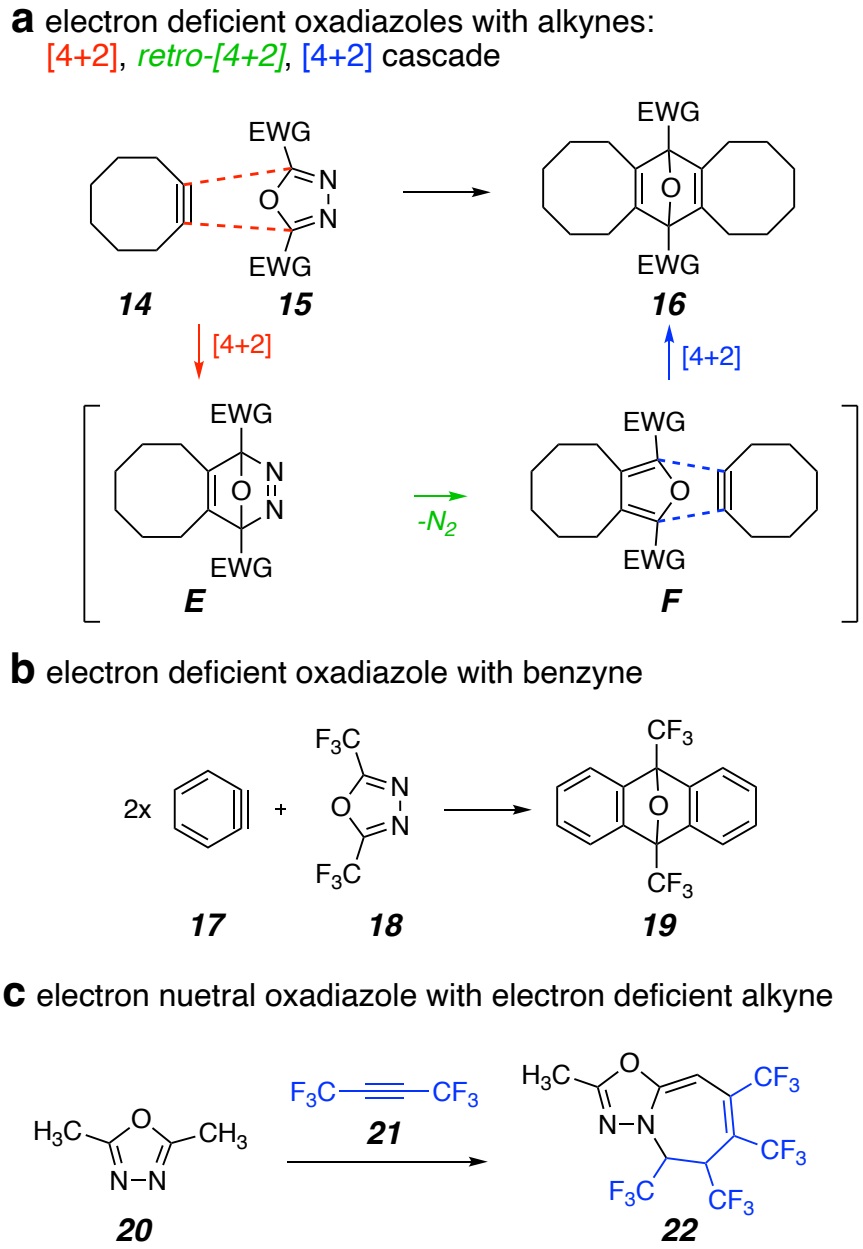


Figure 12. (a) Cascade reaction of cyclooctyne reacting with electron deficient 1,3,4-oxadiazoles to afford **16**. (b) *o*-Benzyne (**17**) reacting with 2,5-bis(trifluoromethyl)-1,3,4-oxadiazole (**18**) in an analogous cascade reaction. (c) Reaction of 2,5-dimethyl-1,3,4-oxadiazole (**20**) with two equivalents of hexafluorobut-2-yne (**21**) proceeding via a formal ene-reaction en route to **22**.

[47] Koshelev, V. M.; Chekhlov, A. N.; Vasil'ev, N. V.; Gontar', A. F.; Martynov, I. V. Reaction of 2,5-dimethyl-1,3,4-oxadiazole with perfluoro-2-butyne. *Russ. Chem. Bull.* **1989**, *38*, 671–671.

2.7 Results and Discussion

Our investigations commenced by heating prototypical triyne **23** with 2,5-diphenyl-1,3,4-oxadiazole (**24**) in a 1:1 molar equivalent ratio (Figure 13). Two products were isolated. The minor component was identified as a 1:1 benzyne–oxadiazole adduct **25** (9%) containing a benzo-fused azetidine subunit. Product **25** appears to represent the first example of a reaction in which an oxadiazole has participated in a thermally driven, net [2 + 2] cycloaddition, although there is a report of a somewhat related photochemical transformation.[48]

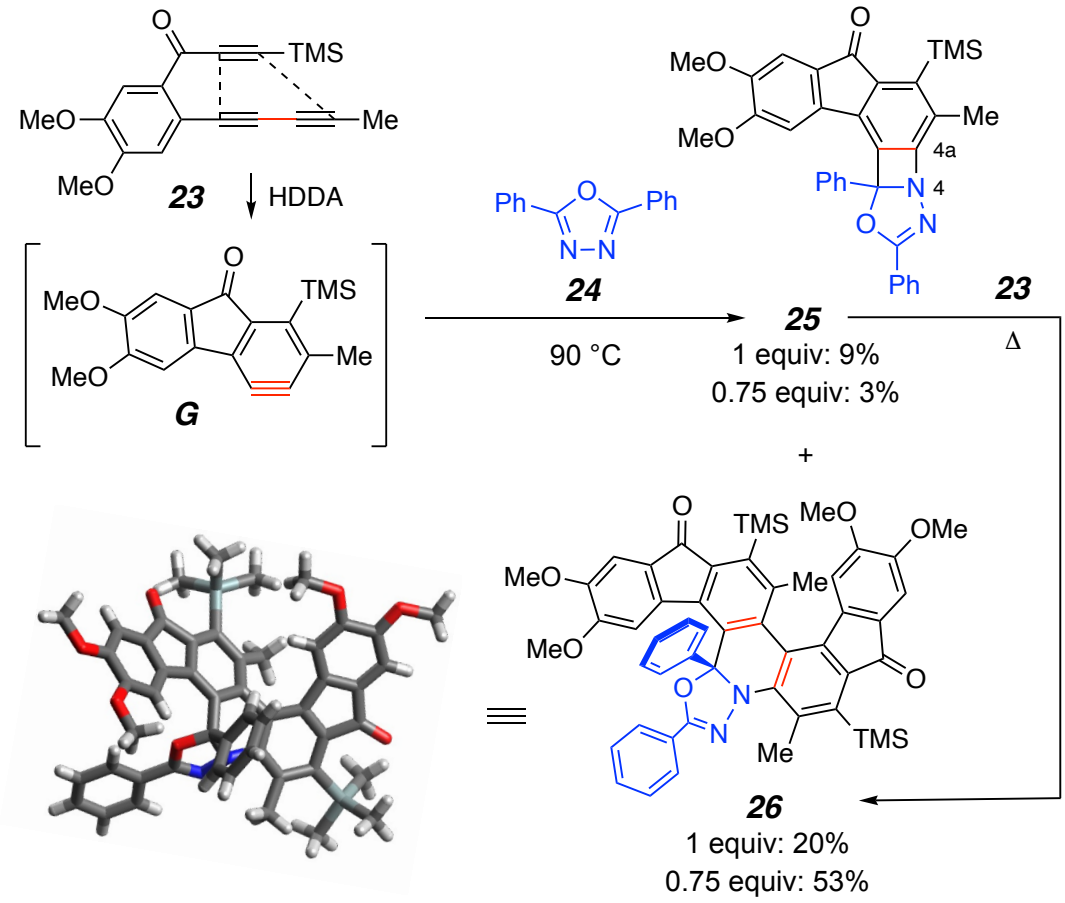


Figure 13. Reaction of benzyne **G**, derived from triyne **23**, with 2,5-diphenyl-1,3,4-oxadiazole (**24**) to afford 1:1 adduct **25** and **26**.

The major component **26** (20%) was identified as a 2:1 benzyne–oxadiazole adduct based on the corresponding mass data; however, the exact structure was challenging to assign even with

[48] Tsuge, O.; Oe, K.; Tashiro, M. Photochemistry of heterocyclic compounds–II: The photochemical reaction of 2,5-disubstituted 1,3,4-oxadiazoles with furan. *Tetrahedron* **1972**, *29*, 41–46.

the associated 2D NMR data (HMBC, HSQC, and NOESY). Because the oxadiazole core lacks protons and has a high heteroatom to carbon ratio, the ^{1}H and 2D NMR analyses were inconclusive. Single crystal X-ray diffraction analysis elucidated the structure of **26** and revealed that the 2:1 adduct has a pseudo-helical geometry.

The ratio of products **25** and **26** was somewhat dependent on the initial stoichiometric ratio of the reactants **23** and **24**, as indicated in Figure 13. A control experiment demonstrated that the 1:1 adduct **25** was transformed into **26** when heated in the presence of additional triyne **23** (and in the absence of the oxadiazole **24**). Thus, the 2:1 adduct arises from a formal insertion of a second benzyne molecule into the C(4a)–N(4) bond in **25**. We speculated that this might be initiated by nucleophilic attack of N-4 in **25** to the benzyne **G**.

We turned to DFT computations to gain more insight to guide a mechanistic hypothesis. We chose to evaluate the reaction between the simple *o*-benzyne (**17**) and diphenyl-1,3,4-oxadiazole (**24**) to give the 2:1 adduct **30** (Figure 14). Initially, the oxadiazole was seen to engage *o*-benzyne to form the zwitterionic intermediate **27** via **TS1**. This species proceeded to the benzazetidine derivative **28** by a 4-*endo*-*trig* cyclization via **TS2**. The azetidine nitrogen of **28** then adducted with a second equivalent of *o*-benzyne to form the zwitterionic intermediate **29** via **TS3**. The final product **30** arose from **29** by a concerted process in which aryl-aryl bond formation and nitrogen cleavage occur in unison. It is noteworthy that the activation energy for this transformation, a concerted S_NAr process,[49] is only 12.0 kcal mol^{-1} and that product formation is exceedingly exergonic (ca. 104 kcal mol^{-1}).

[49] (a) Neumann, C. N.; Hooker, J. M.; Ritter, T. Concerted nucleophilic aromatic substitution with $^{19}F^{-}$ and $^{18}F^{-}$. *Nature* **2016**, *534*, 369–373. (b) Neumann, C. N.; Ritter, T. Facile C–F bond formation through a concerted nucleophilic aromatic substitution mediated by the PhenoFluor reagent. *Acc. Chem. Res.* **2017**, *50*, 2822–2833. (c) Kwan, E. E.; Zeng, Y.; Besser, H. A.; Jacobsen, E. N. Concerted nucleophilic aromatic substitutions. *Nat. Chem*. **2018**, *10*, 917–923.

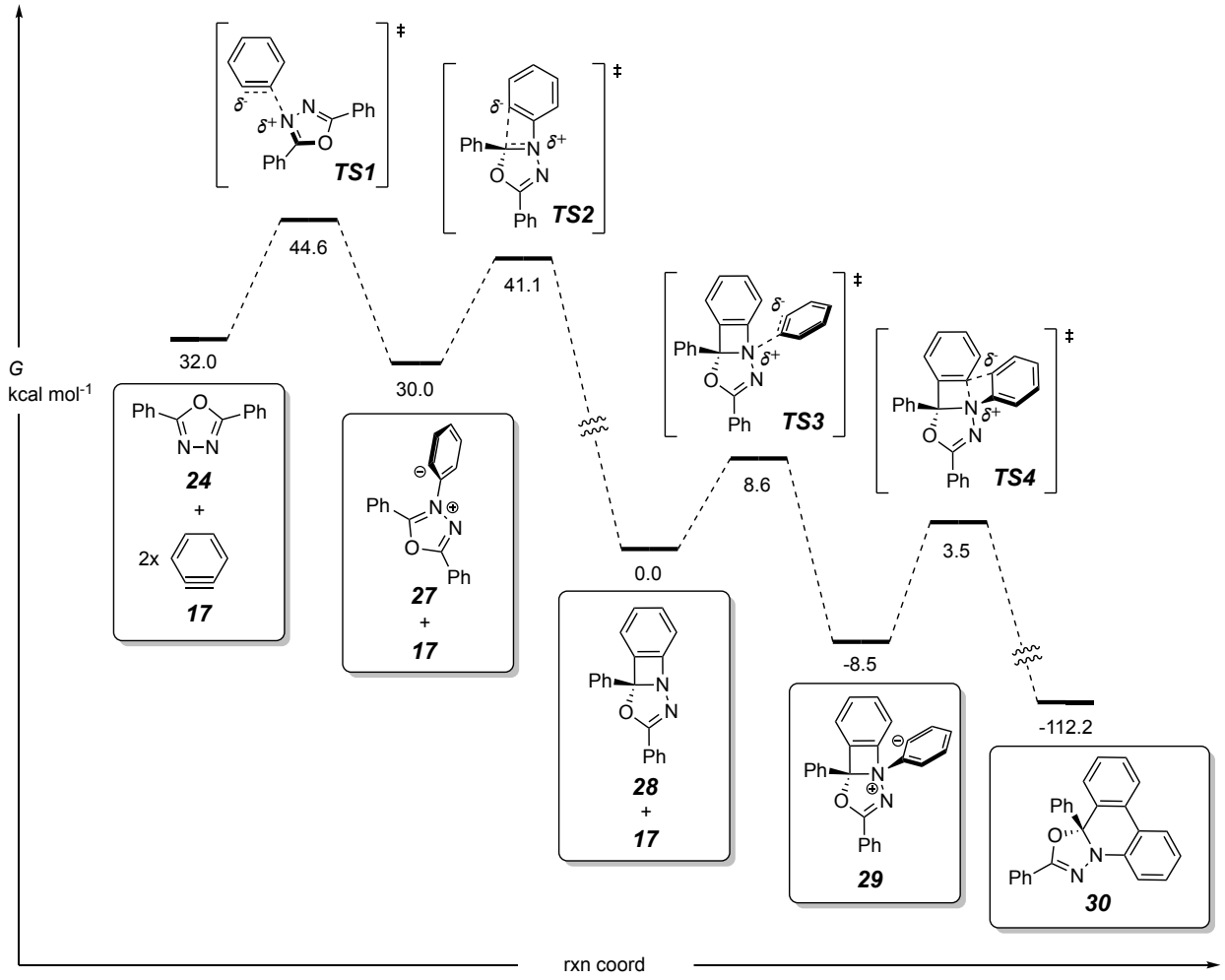
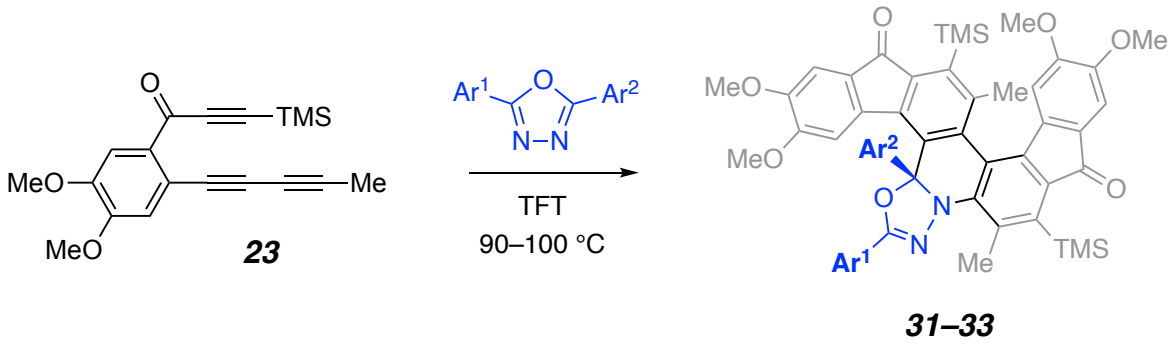


Figure 14. DFT[i] potential energy surface (PES) of *o*-benzyne (**17**) reacting with 2,5-diphenyl-1,3,4-oxadiazole (**24**) leading to **30**. [i]IEFPCM(chloroform)/M06-2X/6-311+G(d,p).

We next explored the reactivity of other 2,5-diarylated 1,3,4-oxadiazoles (Figure 15). 2,5-Bis(4-methoxyphenyl)-1,3,4-oxadiazole furnished **31** in a 46% yield. Unsymmetric oxadiazoles led to the formation of two regioisomeric products in which the Ar^1 and Ar^2 substituents are swapped. For example, 2-(naphthalen-1-yl)-5-phenyl-1,3,4-oxadiazole leads to **32a/b** as a 5.7:1 mixture of co-eluting regioisomers in a 31% combined yield. The observed regioselectivity is presumably governed by the steric bulk of the naphthyl carbocycle, which diminishes the initial attack at the nitrogen atom adjacent to the larger of the two aryl substituents. Similarly, 2-phenyl-5-(thiophen-2-yl)-1,3,4-oxadiazole afforded **33a/b** as a nearly 1:1 mixture of co-eluting regioisomers in a 39% combined yield. The thiophene substituent, sterically comparable to that of a phenyl group, has essentially no influence in directing the regioselectivity of this reaction.



	Ar¹	Ar²	isol. yield	*a* : *b* ratio
31	PMP	PMP	46%	na
32a	1-Naph	Ph	31%	5.7 : 1
32b	Ph	1-Naph		
33a	2-thiophenyl	Ph	39%	1 : 1
33b	Ph	2-thiophenyl		

Figure 15. 2:1 adducts arising from the reaction of HDDA-generated benzynes with other 2,5-diaryloxadiazoles.

In the examples above, the HDDA-derived benzyne does not engage in [4+2] cycloaddition chemistry, presumably due to the absence of electron-withdrawing groups on the oxadiazole. However, we wondered whether the steric bulk of the HDDA-benzyne was also playing a significant role in influencing the novel modality of the reaction. We therefore reacted triyne **23** with 2,5-diphenyl*oxazole* (**34**), a trapping agent that closely mimics the steric environment of 2,5-diphenyl-1,3,4-*oxadiazole* (**24**) (Figure 16) and that is known to trap both simple, unhindered benzynes[50] as well as HDDA-benzynes[51] via initial [4+2] cycloaddition. The two regioisomeric epoxyanthracene products **35a** and **35b** were isolated in a combined 67% yield. These arise from loss of HCN via a retro-Diels-Alder reaction of an initial adduct (cf. **H**) to produce an isobenzofuran species that is captured by a second molecule of the benzyne.

[50] Garg, P.; Upreti, G. C.; Singh, A. Synthesis of tritylones via cascade reaction of arynes with 5-ethoxyoxazoles. *J. Org. Chem.* **2022**, *87*, 7219–7228.
[51] Yang, F.; Zheng, X.; Lei, Y.; Hu, Q.; Zhu, W.; Hu, Y. Epoxyanthracene derivatives and dicarbonylation on benzene ring via hexadehydro-Diels–Alder (HDDA) derived benzynes with oxazoles. *Synthesis* **2022**, *54*, 1125–1133.

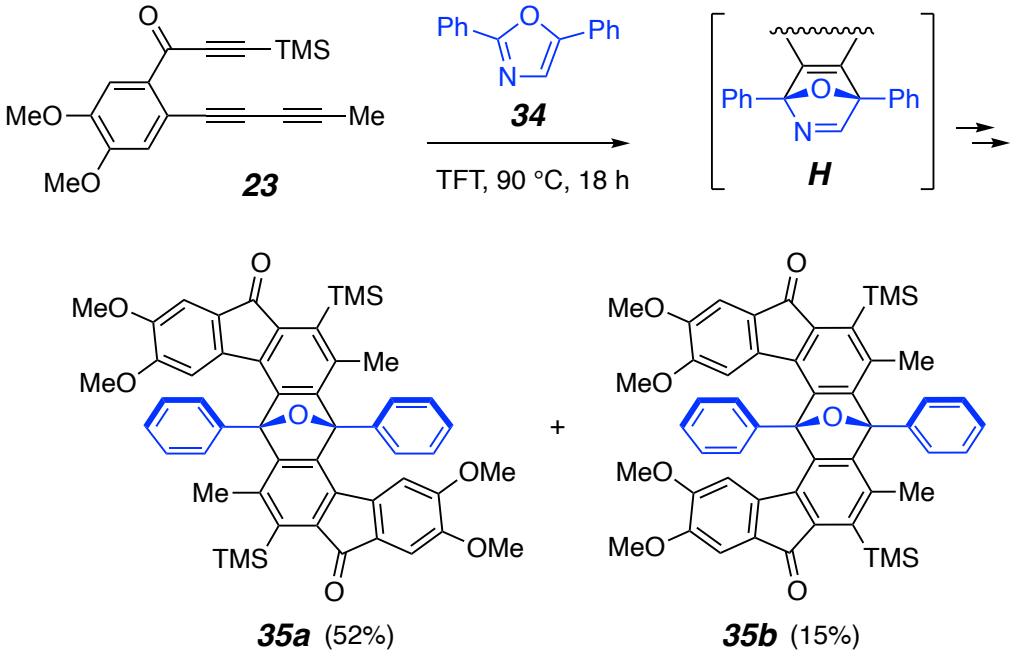


Figure 16. Reaction of triyne **23** with 2,5-diphenyloxazole (**34**) to produce two regioisomeric epoxyanthracene products: **35a** as the major "S" isomer and **35b** as the minor "U" isomer.

To gain understanding for the stark difference between the different modes of reaction of **G** with the oxadiazole **24** vs. the oxazole **34** (i.e., no [4+2] product observed using **24**), we computed the transition structures for the possible concerted [4+2] cycloadditions of each pair (see Figure 17 for oxadiazole and Figure 18 for oxazole). The E_{act} for the (unobserved) oxadiazole Diels-Alder reaction with **G*** (a slightly simplified version of the benzyne **G**) via **TS5** was 14.4 kcal mol^{-1} compared to the E_{act} of 10.5 or 9.9 kcal mol^{-1} for the oxazole via **TS6a** or **TS6b**, respectively. The lowest energy pair of HOMO/LUMO gap for $\mathbf{G^*}_{LUMO}/\mathbf{24}_{HOMO}$ vs. $\mathbf{G^*}_{LUMO}/\mathbf{34}_{HOMO}$ were larger for the former by 0.5 kcal mol^{-1} (Figure 19). This is reflected in the slightly shorter distances between the terminal pairs of diene/benzyne-dienophile carbon atoms in **TS5** compared to those for **TS6a** and **TS6b**. This results in higher steric repulsion in **TS5**, likely attributing to its higher energy.

2,5-diphenyl-1,3,4-oxadiazole (**24**)

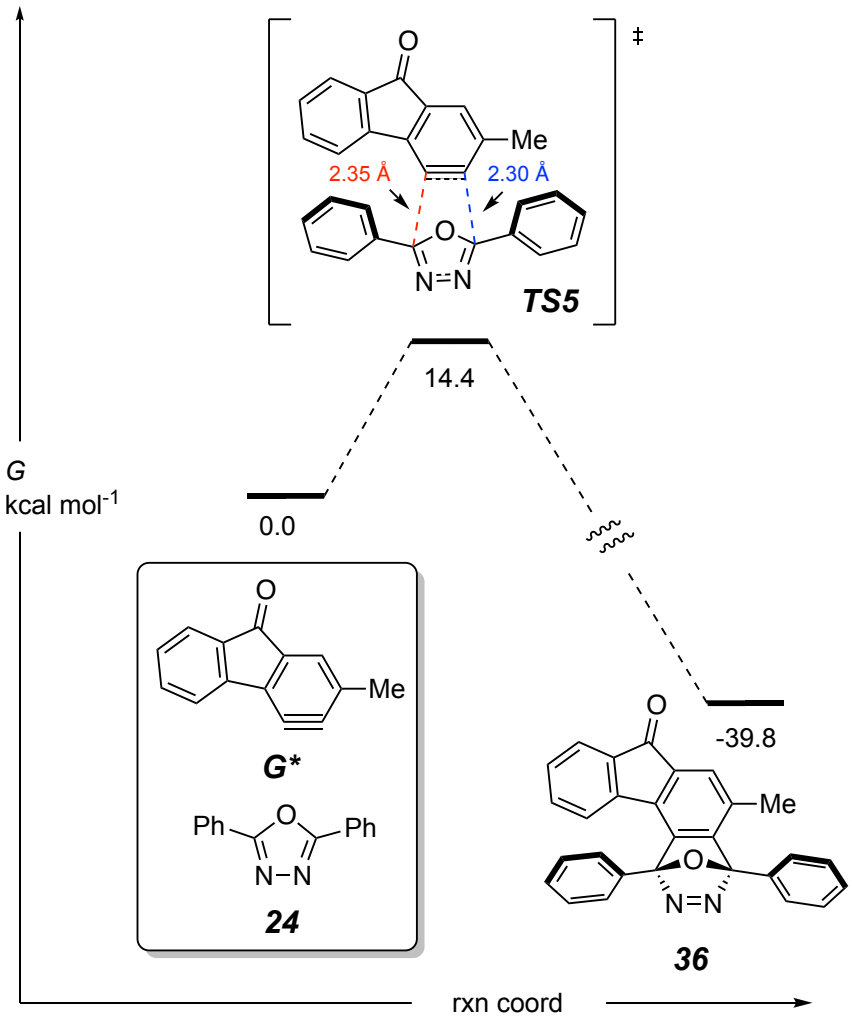


Figure 17. DFT[i] potential energy surfaces computed for the [4+2] cycloaddition reaction of the HDDA-benzyne **G*** with 2,5-diphenyl-1,3,4-oxadiazole (**24**) leading to cycloadduct **36**. [i]IEFPCM(chloroform)/M06-2X/6-31+G(d,p).

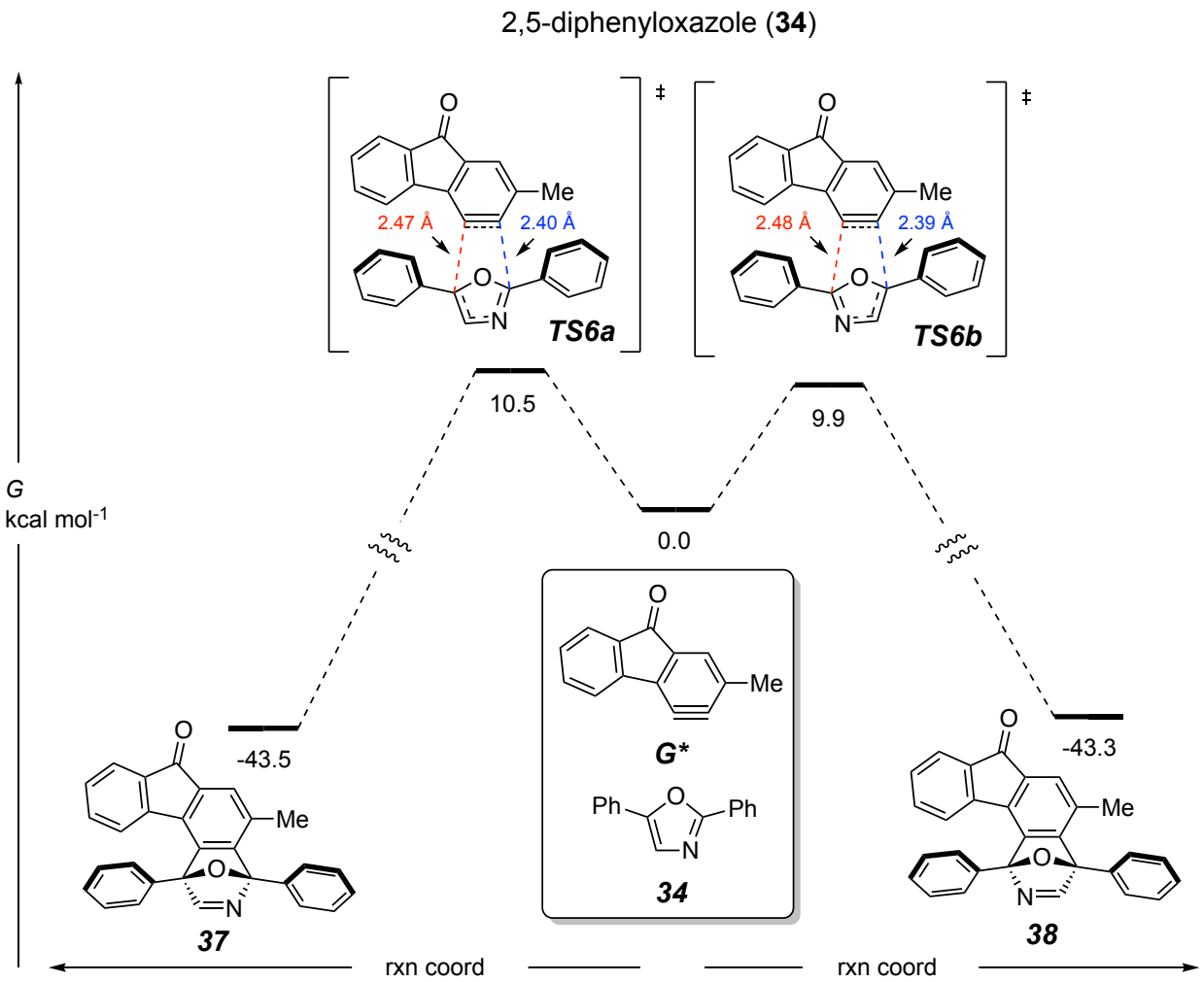
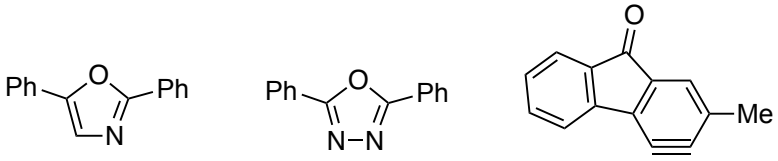


Figure 18. DFT[i] potential energy surfaces computed for the [4+2] cycloaddition reaction of the HDDA-benzyne **G*** with 2,5-diphenyloxazole (**34**) leading to two regioisomeric cycloadducts **37** and **38**. [i]IEFPCM(chloroform)/M06-2X/6-31+G(d,p).



34 ***24*** ***G****

a	LUMO Oxazole **34**	-0.02004 eV	
	HOMO Oxazole **34**	-0.25500 eV	
	LUMO Oxadiazole **24**	-0.02658 eV	
	HOMO Oxadiazole **24**	-0.27890 eV	
	LUMO Benzyne **G***	-0.05732 eV	
	HOMO Benzyne **G***	-0.27898 eV	
b	HOMO **G***//LUMO **34** Gap	-0.25894 eV	5.97 kcal/mol
	HOMO **G***//LUMO **24** Gap	-0.25240 eV	5.82 kcal/mol
	LUMO **G***//HOMO **34** Gap	-0.19768 eV	4.56 kcal/mol
	LUMO **G***//HOMO **24** Gap	-0.22158 eV	5.11 kcal/mol

Figure 19. a) Computed [i] HOMO and LUMO energies for oxazole **34**, oxadiazole **24**, and benzyne **G***. **b**) The HOMO-LUMO gap energies between benzyne **G*** and the two cycloaddition partners, oxazole **34** and oxadiazole **24**. [i]IEFPCM(chloroform)/M06-2X/6-31+G(d,p).

Next, we explored the reactivity of 2,5-dimethyl-1,3,4-oxadiazole (**20**) (Figure 20). Koshelev and co-workers demonstrated that this di*alkyl*ated oxadiazole reacts with electron deficient alkynes in a formal ene-type reaction (cf. Figure 12c). When **20** was used to trap **G** (the benzyne derived from substrate **23**) a completely unexpected outcome was seen (Figure 20a). The major isolable product was the 2:1 adduct **39** (28%). The composition of this product was elucidated by X-ray diffraction analysis. Several things are surprising about this structure: i) the seven (bold/marked, blue) heavy atoms in the dimethyloxadiazole trapping agent are strewn across the two benzyne-derived skeletal fragments as three distinct subunits, no longer bonded to one another, ii) a relatively rare (and electrophilic) *N*-acylimine moiety is present, iii) the benzenoid ring from one of the two benzyne intermediates has been dearomatized, and iv) at a minimum: the three bolded (red) bonds and one C–H bond are cleaved in **20** and five (bold, green) bonds are formed in **39**! This transformation represents the first example of a HDDA reaction that results in a product having a dearomatized benzenoid ring.

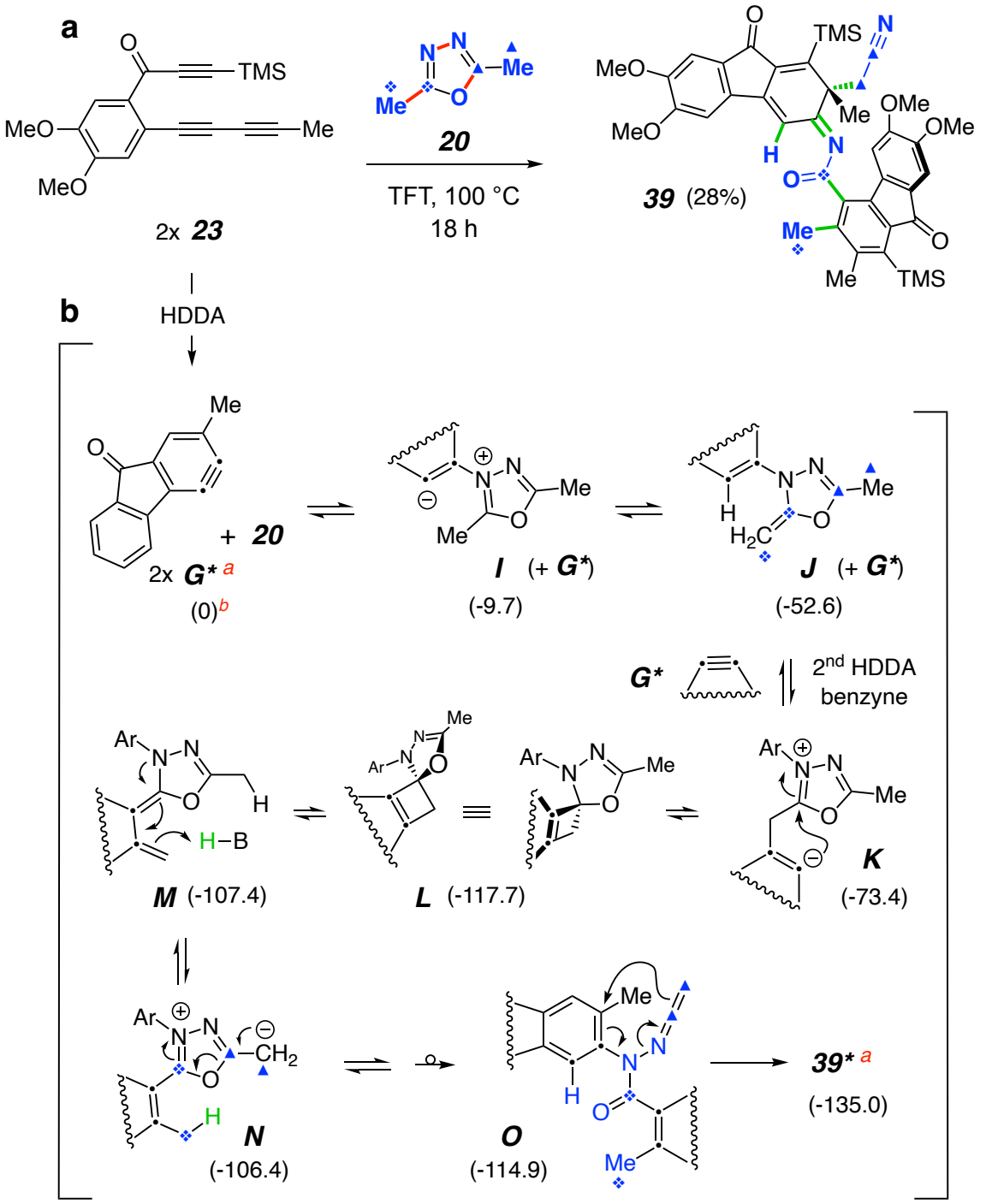


Figure 20. (a) The (remarkable) engagement of two HDDA-benzynes **G** (from **23**) with the dimethyloxadiazole **20** to give the dearomatized adduct **39**. (b) Proposed mechanism for the dismantlement and redistribution of the atoms in the heterocycle **20**. [a] **G*** and **39*** are the analogs lacking the two methoxy and TMS groups present in structures **G** and **39**. [b] The numbers in parentheses are the DFT[i] free energies (kcal mol^{-1}) of each intermediate state. [i]IEFPCM(chloroform)/M06-2X/6-31G(d).

A mechanistic proposal for how this unusual transformation may proceed is presented in Figure 20b. The atoms in **39** arising from the dimethyl-1,3,4-oxadiazole (**20**) starting material are bolded or marked (highlighted in blue). We hypothesize that the oxadiazole nitrogen adducts with the first equivalent of the HDDA-benzyne **G** to form zwitterion **I**, similar to the initial event seen with the diaryl substituted oxadiazoles. The aryl anion in compound **I** can abstract a proton from the adjacent methyl group to form compound **J**, the product of a formal ene-reaction between compounds **G** and **20**. The nucleophilic enamine in compound **J** then engages a second equivalent of compound **G** in a formal [2+2] reaction via the intermediate zwitterion **K** to produce the spirocyclic intermediate **L**. The benzoxetene substructure within intermediate **L** can be expected to undergo a facile 4π-electrocyclic ring-opening to give the *o*-xylylene derivative **M**. A net proton transfer from the distal methyl group to the exocyclic methylene carbon in compound **M**, likely mediated by a proton shuttle such as a molecule of **20** (i.e., BH = an oxadiazolium ion) or a water molecule (i.e., BH = H–OH), would generate the delocalized zwitterion **N**. This could fragment the heterocycle so as to give the ketenimine (and penultimate) intermediate **O**. A final [3,3]-sigmatropic rearrangement with cleavage of the N–N σ- and cumulene π-bonds would provide the dearomatized product **39**.

We mapped the minima on the PES for this multi-step mechanism using DFT. For computational simplification, all of the structures in Figure 20b are of the nor-dimethoxy/nor-TMS analogs of the species we propose to be involved in the actual conversion of compound **23** to compound **39**. The overall reaction energy is highly exergonic and no elementary step proceeds through a prohibitively high energy intermediate state. The most unusual interconversions occur in the final phase of the mechanism: namely, **M** ⇌ **N** ⇌ **O** ⇌ **39*** (see Figure S1 in the SI for a fuller representation of the computed PES). Unsurprisingly, given its geometry, we were unable to locate a transition structure (TS) for a unimolcular proton transfer to convert compound **M** to compound **N**; hence our suggestion (above) that this is mediated by an external proton transporter. The ring-opening of the zwitterion **N** to the ketenimine **O** was seen to proceed via a TS that was 9.9 kcal mol^{-1} higher than G° of compound **N**. The final, dearomative rearrangement to product **39*** showed a barrier of 29.1 kcal mol^{-1} from compound **O**. The counterintuitive final cyclization onto the substituted (rather than unsubstituted) aromatic carbon in the last intermediate prior to

product **39** finds precedent in [3,3]-sigmatropic rearrangements of ortho-methylated phenylhydrazine derivatives.[52]

To further probe this process, we examined the reactivity of the 3H-indole derivative **40** containing a substructure related to one in 2,5-dimethyl-1,3,4-oxadiazole (**20**) to see if we could learn, by analogy, about the first steps of the dearomative mechanism leading to **39**. Reacting triyne **23** with **40** resulted in formation of i) a 1:1 adduct, the enamine **41**, in a 44% yield and ii) a benzocyclobutene spirocyclic compound **42** in a 30% yield (Figure 21). The enamine **41** was confirmed to be an intermediate along the reaction pathway to benzocyclobutene **42** by an experiment in which triyne **23** was cleanly converted to **42** when heated in the presence of excess enamine **41**.

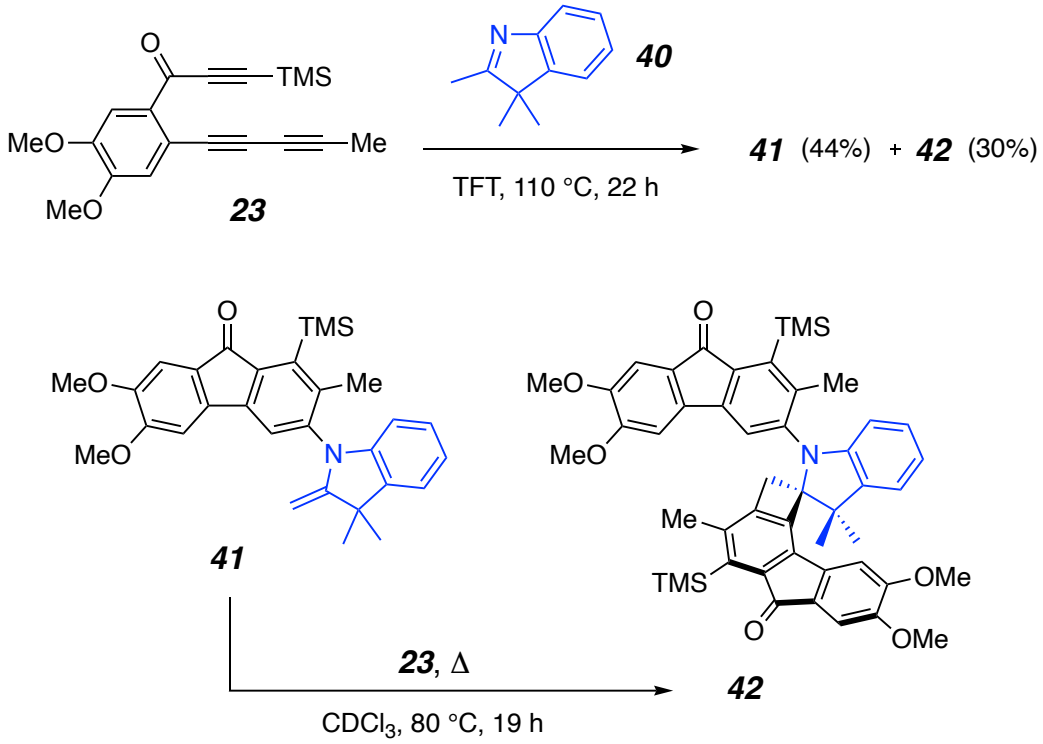


Figure 21. Reaction between triyne **23** with 2,3,3-trimethyl-3*H*-indole (**40**) to form enamine 1:1 adduct **41** and benzocyclobutene 2:1 adduct **42**. When isolated **41** was subsequently heated with triyne **23**, **42** was cleanly formed.

[52] Miller, B.; Matjeka, E. R. "1,4" Alkyl migrations in Fischer indole cyclizations. *J. Am. Chem. Soc.* **1980**, *102*, 4772–4780.

We continued to explore other oxadiazole substitutions, and, in many instances, the substrates led to unproductive reaction outcomes (Figure 22). For example, 2,5-bis(trifluoromethyl)-1,3,4-oxadiazole (**18**) is presumably too electron-poor to efficiently engage the electrophilic HDDA benzye. The [4+2] cycloaddition of the fairly inert and electron-deficient trifluorotoluene solvent outcompeted the reaction with 2,5-bis(trifluoromethyl)-1,3,4-oxadiazole (**18**). The pyridinyl-substituted oxadiazole **43** was also an unproductive substrate. However, in this instance, 2,5-di(pyridin-4-yl)-1,3,4-oxadiazole (**43**) rapidly reacted with the triyne **23** prior to heating. Upon heating with triyne **23**, both 2-methyl-5-phenyl-1,3,4-oxadiazole (**44**) and 2-phenyl-1,3,4-oxadiazole (**45**) led to significant decomposition and complex product mixtures.

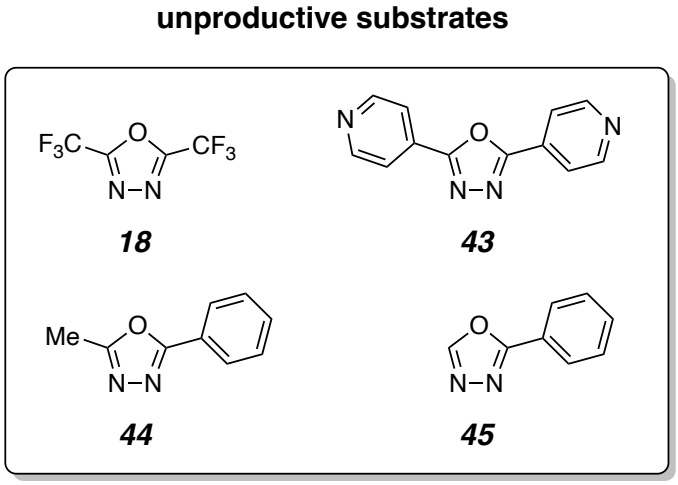


Figure 22. Oxadiazole derivatives **18** and **43–45**, which led to unproductive reaction outcomes.

2.8 Conclusion

In conclusion, we have discovered novel oxadiazole and benzyne reactivity, leading to a series of structurally fascinating 2:1 adducts. 2,5-Diaryloxadiazoles adduct with HDDA-benzynes in formal [2+2] cycloadditions to afford benzazetidine-containing 1:1 adducts. We experimentally demonstrate that the benzazetidine 1:1 adducts may engage a second equivalent of benzye to afford the corresponding 2:1 adducts via a formal C–N insertion. DFT computations elucidated that a concerted S_NAr process is involved in the formal C–N insertion reaction. Evidence herein suggests that HDDA-benzyes do not participate in [4+2] cycloaddition chemistry with 2,5-diaryloxadiazoles due electronic rather than steric factors. We additionally disclose the first isolated example of a dearomatized HDDA product **39** arising from the trapping of 2,5-dimethyl-1,3,4-oxadiazole (**20**).

Chapter III & IV Background: Free Carbenes

3.1 Free Carbene Structure and Reactivity

Since the first reported free carbene[53] in 1903, carbenes have long held the fascination of physical organic chemists and practitioners of synthetic chemistry due to their bimodal electronic structure as well as enabling modes of reactivity. In either an *sp* or sp^2 hybridized state, carbenes are divalent and have one orthogonal *p* orbital (relative to the bonding plane) and a perpendicular *p* or sp^2 hybridized orbital that are available for occupation by the carbene's remaining two electrons.[54] These may reside together in either the in-plane orbital or the orthogonal *p* orbital. Such an electron configuration produces a singlet state. A triplet carbene distinctly houses a single electron in both the in-plane orbital and the orthogonal *p* orbital (Figure 23a).

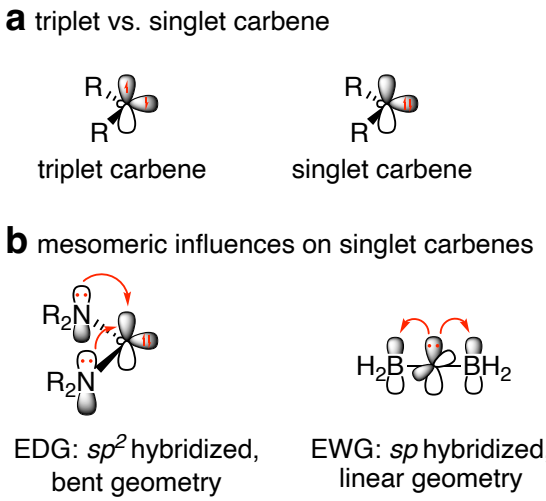


Figure 23. (a) Triplet vs. singlet carbenes and (b) the geometric and hybridization outcomes produced by mesomeric effects on free carbenes.

It is possible for systems to interconvert between singlet and triplet states depending on the corresponding thermodynamic and kinetic profile. The nature of the substituents directly bonded to the carbene governs the thermodynamic preference for the singlet or triplet spin multiplicity and consequently the carbene's geometry and hybridization.[55] Inductive effects only play a determining role in very few instances (e.g. Li-C-Li), while mesomeric effects are the

[53] Buchner, E.; Feldmann, L. Diazoessigester und Toluol. *Ber. Dtsch. Chem. Ges.* **1903**, *36*, 3509–3517.
[54] Anslyn, Eric V., and Dennis A. Dougherty. *Modern Physical Organic Chemistry*. University Science Books: Sausalito, CA, 2006; p 574–576.
[55] Bourissou, D.; Guerret, O.; Gabbaï, F. P.; Bertrand, G. Stable carbenes. *Chem. Rev.* **2000**, *100*, 39–92.

primary influencers. π-Electron-donating groups, such as -F, -NR_2, and -OR, donate electron density into the carbene's *p* orbital, effectively lowering the energy of the singlet state and inducing a bent geometry. π-Electron-withdrawing groups, such as -COR and -CN, cause carbenes to adopt a more linear geometry and a *sp* hybridization state. Only one of the orthogonal *p* orbitals, p_y, may interact (i.e., donate electron density) with the neighboring electron-poor π system, producing a disruption in orbital degeneracy and inducing a singlet state (Figure 23b). Very few free carbenes are persistent triplet carbenes; however, photosensitizers (and photolysis methods) may be used to gain direct access to triplet carbenes.

The triplet or singlet spin multiplicity of carbenes influences their reactivity, which has significant implications in dictating product distribution and mechanism. Both triplet and singlet carbenes are capable of C–H insertions and cyclopropanation reactions, yet the triplet and singlet respective mechanisms are distinct.[54] Singlet carbenes undergo C–H insertion and cyclopropanation in a concerted fashion, whereas triplet carbenes, behaving as diradical species, proceed via stepwise, (di)radical mechanisms. The mesomeric effects of π-electron-withdrawing and donating substituents are the primary influencer in dictating both the spin multiplicity of carbenes and, consequently, their reactivity. For example, most carbenes are relatively electrophilic (containing a carbon atom with only six valence shell electrons), yet carbenes with two adjacent heteroatoms, as in the case of *N*-heterocyclic carbenes (NHCs), are nucleophilic in nature.

3.2 Free Carbene Generation

Other than the deprotonation of amidinium ions for the formation of NHCs and α-elimination of haloform substrates, most classical methods of generating free carbenes involve the loss of molecular nitrogen (Figure 24). Starting in the late 1990's, the Davies group popularized the use of rhodium carbenoids derived from diazo compounds by demonstrating intermolecular C–H insertion reactions that were both highly chemoselective and regioselective.[56] A host of enantioselective methodologies, including cyclopropanation strategies, were developed soon after, enabled by the use of non-racemic, chiral catalysts.[56] There has been, nevertheless, a growing interest in free carbenes generated under visible light conditions, given the metal-free and cost-

[56] Ford, A.; Miel, H.; Ring, A.; Slattery, C. N.; Maguire, A. R.; McKervey, M. A. Modern organic synthesis with α-diazocarbonyl compounds. *Chem. Rev.* **2015**, *115*, 9981–10080.

effective nature of these transformations.[57] The photolysis of diazo compounds to generate free carbenes has been well-known for nearly a century with one of the first reports being disclosed by Hans Meerwein in 1942.[58] In this pioneering work, Meerwein describes the UV irradiation of diazomethane (on an 8 mol scale!) and observed C–H insertion into the diethyl ether reaction solvent. The UV photolysis of diazo compounds has since been thoroughly explored, but these methodologies using UV light sources have found limited application in organic synthesis due to unselective absorption of high-energy light that leads to substrate decomposition and functional group restraints.[57] In 2018, Jurberg and Davies showed that visible light was capable of photolyzing aryldiazoacetates[59], which solved the issues associated with UV irradiation and inspired a burgeoning field of visible light-induced free carbene methodologies.

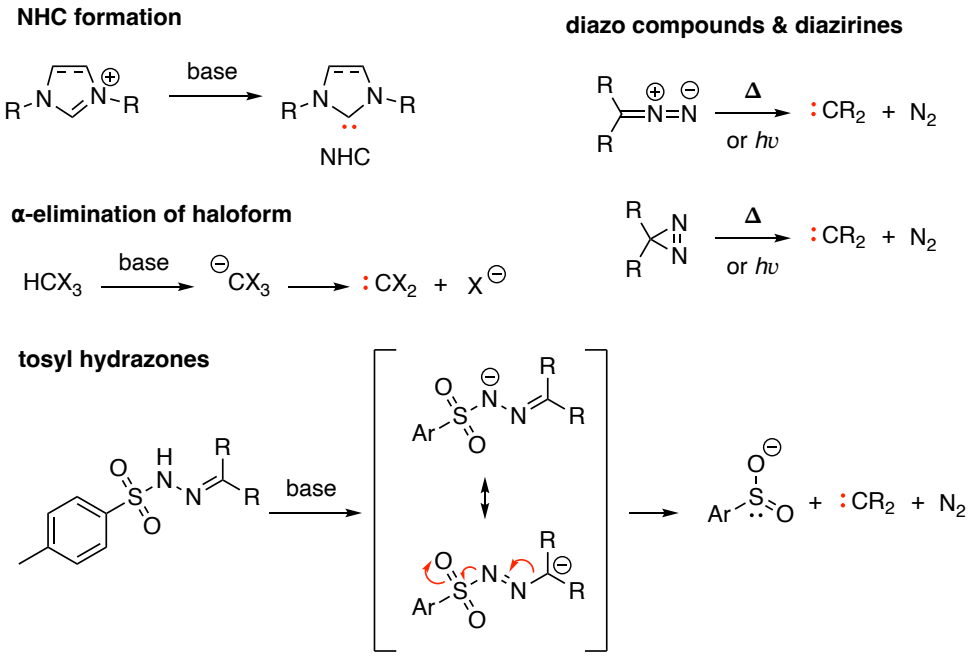


Figure 24. Classical methods of free carbene generation.

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[57] (a) Chen, Z.; Xie, Y.; Xuan, J. Visible light-mediated cyclopropanation: Recent progress. *Eur. J. Org. Chem.* **2022**, 2022, No. e202201066. (b) Yang, Z.; Stivanin, M. L.; Jurberg, I. D.; Koenigs, R. M. Visible light-promoted reactions with diazo compounds: A mild and practical strategy towards free carbene intermediates. *Chem. Soc. Rev.* **2020**, *49*, 6833−6847. (c) Zhang, Z.; Gevorgyan, V. Visible light-induced reactions of diazo compounds and their precursors. *Chem. Rev.* **2024**, *124*, 7214−7261. (d) Gallo, R. D. C.; Cariello, G.; Goulart, T. A. C.; Jurberg, I. D. Visible light-mediated photolysis of organic molecules: The case study of diazo compounds. *Chem. Commun.* **2023**, *59*, 7346–7360. For methodology to synthesize polycyclic cyclopropanes, see: (e) Pei, C.; Empel, C.; Koenigs, R. M. Photochemical intermolecular cyclopropanation reactions of allylic alcohols for the synthesis of [3.1.0]-bicyclohexanes. *Org. Lett.* **2023**, *25*, 169−173.

[58] Meerwein, H.; Rathjen, H.; Werner, H. Die Methylierung von RH-Verbindungen mittels Diazomethans unter Mitwirkung des Lichtes. *Ber. dtsch. Chem. Ges. A/B* **1942**, *75*, 1610–1622.

[59] Davies, H. M. L. Blue light-promoted photolysis of aryldiazoacetates. *Chem. Sci.* **2018**, *9*, 5112–5118.

Alkynes can also be used as carbene precursors, albeit less commonplace than diazo substrates.[60] Generally, π-acid catalysts (e.g., CuCl or Au-based catalysts) activate alkynes towards inter- or intra-molecular nucleophilic attack, generating, most commonly, α-imino- or α-oxo-carbenoids (Figure 25a).[60,61,62] More rare are examples of free carbene generation by a process that conserves all of the elements of the reactant(s) (i.e., is 100% atom economical). The earliest examples of such a reaction are the oxidative dimerization[63a] and the tetramerization[63b] of dimethyl acetylenedicarboxylate (**46**, DMAD; Figure 25b). These processes involve a formal (3+2) cycloaddition to arrive at the intermediate free carbene **P** (cf. **R** + **S** → **U**; Figure 26). A related example is the reaction of DMAD with cyclooctyne.[64] Photolysis of acylsilanes can result in C-to-O silyl migration and this represents another method of carbene generation that conserves all atoms.[65] Finally and starting with the initial report of Nakatani and Saito,[66a] a number of instances involving the conversion of an alkyne to a heteroaryl-substituted free carbene[66b] are intramolecular in nature. One case of note here, involves formation and trapping of several (3-indolizinyl)methylcarbenes from 2-enynylpyridines (Figure 25c).[67]

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[60] Ye, L. W. Alkynes as Carbene Precursors for the Synthesis of Heterocycles. *Heterocycles from Carbenes and Nitrenes: Methods, Reactions and Synthetic Applications;* Doyle, M. P., Xu, X., Eds.; Topics in Heterocyclic Chemistry; Springer International Publishing: Cham, 2023; pp. 225–268.

[61] Shirtcliff, L. D.; Haley, M. M.; Herges, R. CuCl-Induced formation and migration of isoindazolyl carbenoids. *J. Org. Chem.* **2007**, *72*, 2411–2418.

[62] Chintawar, C. C.; Mane, M. V.; Tathe, A. G.; Biswas, S.; Patil, N. T. Gold-catalyzed cycloisomerization of pyridine-bridged 1,8-diynes: An expedient access to luminescent cycl[3.2.2]azines. *Org. Lett.* **2019**, *21*, 7109–7113.

[63] (a) Winterfeldt, E.; Giesler, G. Formation of tetramethyl furantetracarboxylate form dimethyl acetylenedicarboxylate. *Angew. Chem. Int. Ed. Engl.* **1966**, *5*, 579–579. (b) Le Goff, E.; LaCount, R. B. A thermal tetramer of dimethyl acetylenedicarboxylate. *Tetrahedron Lett.* **1967**, *8*, 2333–2335. (c) Kauer, J. C.; Simmons, H. E. The tetramers of acetylenedicarboxylic esters. *J. Org. Chem.* **1968**, *33*, 2720–2726. (d) Gericke, R.; Winterfeldt, E. Additionen an die Dreifachbindung—XVI: Bildung und Reaktionen des Tetrameren Acetylendicarbonsäuremethylesters. *Tetrahedron* **1971**, *27*, 4109–4116.

[64] Banert, K.; Bochmann, S.; Ihle, A.; Plefka, O.; Taubert, F.; Walther, T.; Korb, M.; Rüffer, T.; Lang, H. Synthesis with perfect atom economy: Generation of furan derivatives by 1,3-dipolar cycloaddition of acetylenedicarboxylates at cyclooctynes. *Molecules* **2014**, *19*, 14022–14035.

[65] (a) Hong, W. P.; Lim, H. N.; Shin, I. Recent progress and perspectives in photo-induced organic reactions of acylsilanes. *Org. Chem. Front.* **2023**, *10*, 819–836. (b) Priebbenow, D. L. Silicon-derived singlet nucleophilic carbene reagents in organic synthesis. *Adv. Synth. Catal.* **2020**, *362*, 1927–1946. (c) Zhang, H.-J.; Priebbenow, D. L.; Bolm, C. Acylsilanes: Valuable organosilicon reagents in organic synthesis. *Chem. Soc. Rev.* **2013**, *42*, 8540–8571. (d) Zhou, G.; Guo, Z.; Shen, X. Electron-rich oxycarbenes: New synthetic and catalytic applications beyond Group 6 Fischer carbene complexes. *Angew. Chem. In.t Ed.* **2023**, *62*, e202217189.

[66] (a) Nakatani, K.; Adachi, K.; Tanabe, K.; Saito, I. Tandem cyclizations involving carbene as an intermediate: Photochemical reactions of substituted 1,2-diketones conjugated with ene-yne. *J. Am. Chem. Soc.* **1999**, *121*, 8221–8228. (b) Sheridan, R. S. Heteroarylcarbenes. *Chem. Rev.* **2013**, *113*, 7179–7208.

[67] (a) Lahoz, I. R.; Sicre, C.; Navarro-Vázquez, A.; López, C. S.; Cid, M.-M. Mechanistic investigation on the formation of indolizines from 2-enynylpyridines. *Org. Lett.* **2009**, *11*, 4802–4805. (b) Lahoz, I. R.; López, C. S.;

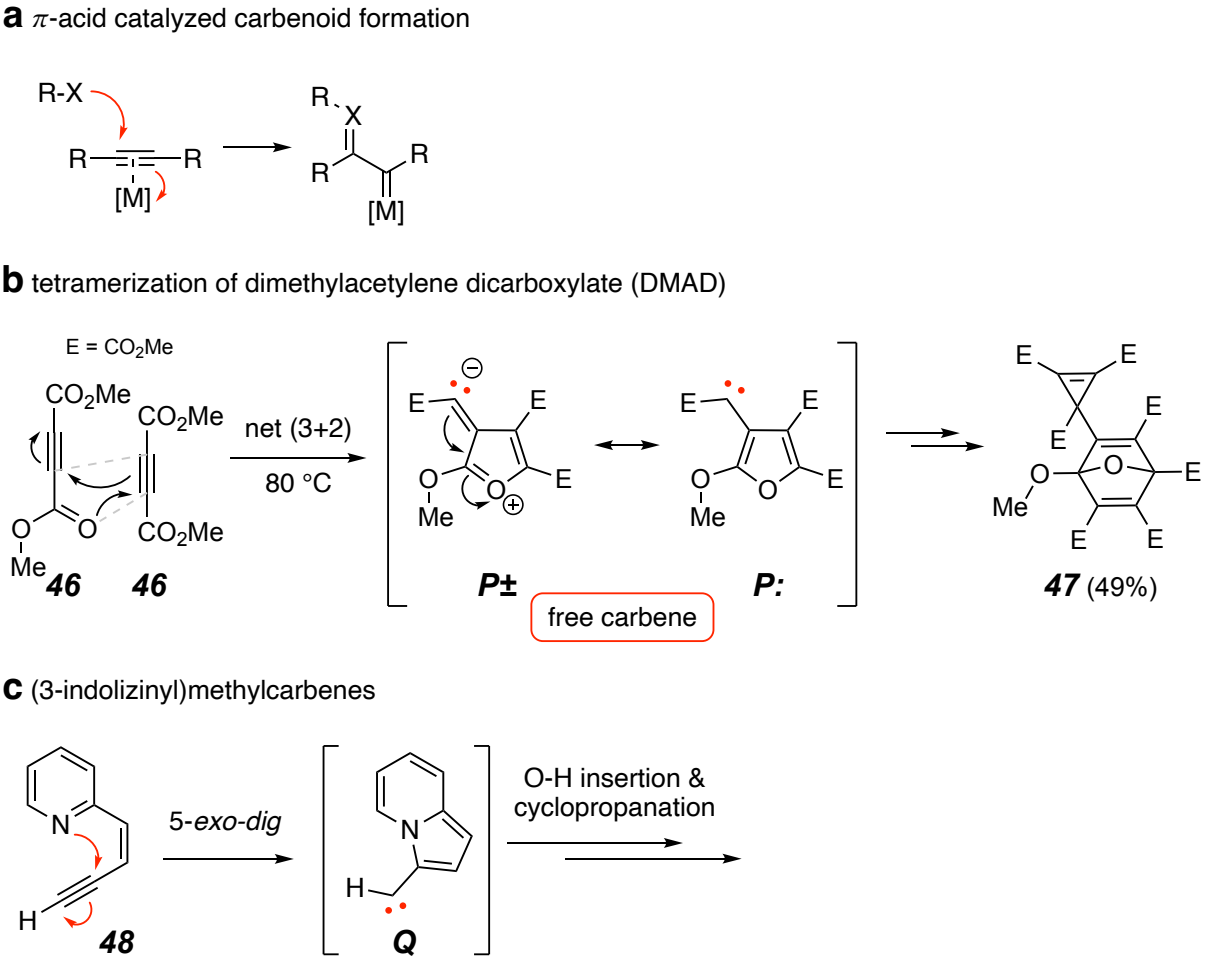


Figure 25. Carbenes derived from alkynes via (a) π-acid catalysts, (b) net (3+2) cycloaddition, and (c) 5-*exo-dig* cyclization to afford (3-indolizinyl)methylcarbenes.

Xu and Hoye recently disclosed that appropriately paired alkynes can engage one another to produce free carbene intermediates (Figure 26).[68] A wide variety of shelf-stable, electrophilic alkynes **S** (EWG = electron-withdrawing group) were shown to engage the nitrogen atom of many different classes of nitrogen heterocycles containing the 2-alkynyl imine substructure shown in **R** to produce the generic carbene **U**.[69] This intermediate has the character of its two principal

Navarro-Vázquez, A.; Cid, M.-M. Experimental and computational exploration of indolizinyl carbene generation. A route to biindolizines. *J. Org. Chem.* **2011**, *76*, 3266–3273.

[68] Xu, Q.; Hoye, T. R. Free carbenes from complementarily paired alkynes. *Nat. Chem.* **2024**, *16*, 1083–1092.

[69] The net (3+2) cyclization to produce the carbene **C** likely proceeds via an intermediate pyridinium zwitterion either by a direct 5-*exo*-cyclization or by a 6-*endo*-ring closure to give an intermediate strained cyclic allene that could then ring-contract to the five-membered exocyclic carbene. For examples of the latter process, see Wills, M. S. B.; Danheiser, R. L. Intramolecular [4 + 2] cycloaddition reactions of conjugated ynones. Formation of polycyclic furans via the generation and rearrangement of strained heterocyclic allenes. *J. Am. Chem. Soc.* **1998**, *120*, 9378–9379.

resonance contributors [zwitterionic (**U**±) and carbenic (**U:**)]. Carbene **U** demonstrated a host of reactivities that are hallmarks of carbene character, including, but not limited to, C–H insertion, O-H insertion, (3,2) sigmatropic rearrangement, and 1,3-dipole formation and cycloaddition.

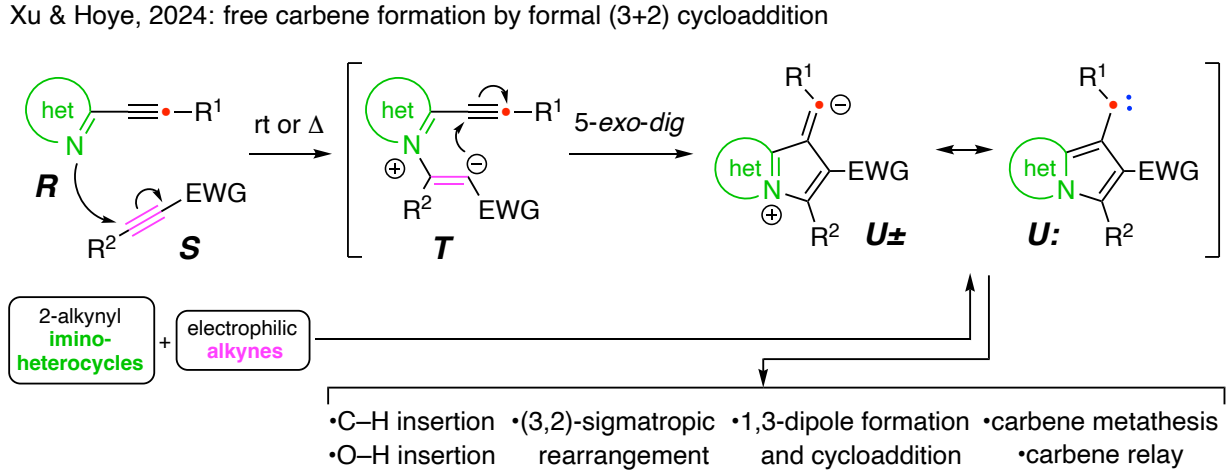


Figure 26. 2-Alkynyl iminoheterocycles **R** react with electron-deficient alkynes **S** in a formal (3+2) reaction giving rise to intermediate free carbenes.

Chapter III: Alkynes to (Free) Carbenes to Polycyclic Cyclopropanes

The following chapter reflects work that was published in the Journal of the American Chemical Society with contributions made by Alexis N. Mann.

Guzman, A. L.; Mann, A. N.; Hoye, T. R. Alkynes to (free) carbenes to polycyclic cyclopropanes. *J. Am. Chem. Soc.* **2024**, *146*, 28642–28647.

3.3 Introduction

Cyclopropane-containing compounds have long been of interest from a variety of perspectives due to their status as the simplest strained hydrocarbon, their methods of preparation,[70] and the unique reactivity they instill as a consequence of their strained nature.[71] They also have played a prominent role in propelling pharmaceutical drug development[72] [cf. the examples of heterocyclic cyclopropanes shown in the small sampling of the preclinical, clinical, and approved (tasimelteon) pharmaceuticals; Figure 27a].

Included in the seminal work by Xu and Hoye is one example of an intermolecular cyclopropanation reaction.[68] When the 2-alkynylpyridine derivative **49** was warmed with DMAD (**46**) in a 1,1-dichloroethene (**50**) solution, the cyclopropane **51**, the result of an intermolecular capture of the free carbene, was formed as the only isolable product. In view of this proof-of-principle cyclopropanation reaction, we were naturally drawn to study analogous intramolecular variants.

[70] Wu, W.; Lin, Z.; Jiang, H. Recent advances in the synthesis of cyclopropanes. *Org. Biomol. Chem.* **2018**, *16*, 7315–7329.
[71] Ebner, C.; Carreira, E. M. Cyclopropanation strategies in recent total syntheses. *Chem. Rev.* **2017**, *117*, 11651–11679.
[72] Talele, T. T. The "cyclopropyl fragment" is a versatile player that frequently appears in preclinical/clinical drug molecules. *J. Med. Chem.* **2016**, *59*, 8712–8756.

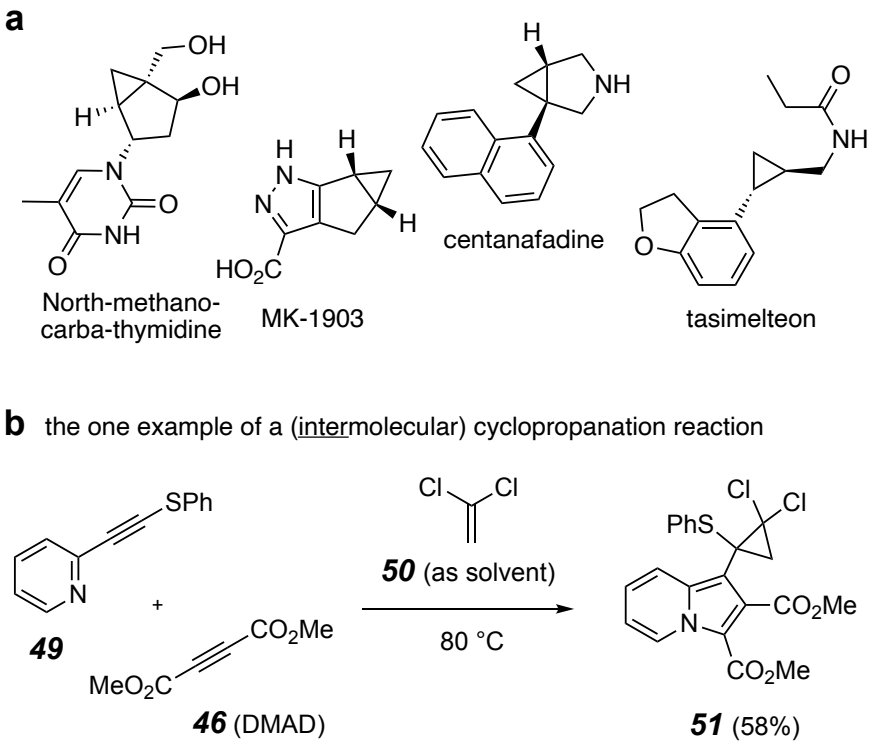


Figure 27. a) Heterocyclic cyclopropanes representative of a large number of compounds pursued in drug-discovery campaigns. b) Our first example of a cyclopropanation reaction initiated by a free carbene derived from an alkyne.

3.4 Results and Discussion

At the onset, we envisioned tethering alkene traps to the alkyne terminus. In one of our initial intramolecular cyclopropanation attempts, the allyl ether substrate **52** was heated in the presence of three equivalents of DMAD (**46**). The tethered allyl alkene was selected for our initial studies because, in leu of differing substituents at the alkene terminus, the mono-substituted alkene avoids forming an additional stereogenic center that could generate diastereomeric products. Through the intermediacy of free carbene **V**, the tetrahydrofuran-fused cyclopropane **53** (59%) was isolated as the sole product. With the DMAD concentration held constant, the reaction at room temperature reached full conversion after 47 h, and product formation was similarly efficient. The relative configuration of the two newly formed stereogenic centers was governed by the insurmountable strain associated with *trans*-fused 5-3 carbocycles.[73]

[73] Ashe, III, A. J. Ring contractions of trans-fused cyclopropanes. *Tetrahedron.* **1969**, *7*, 523–526.

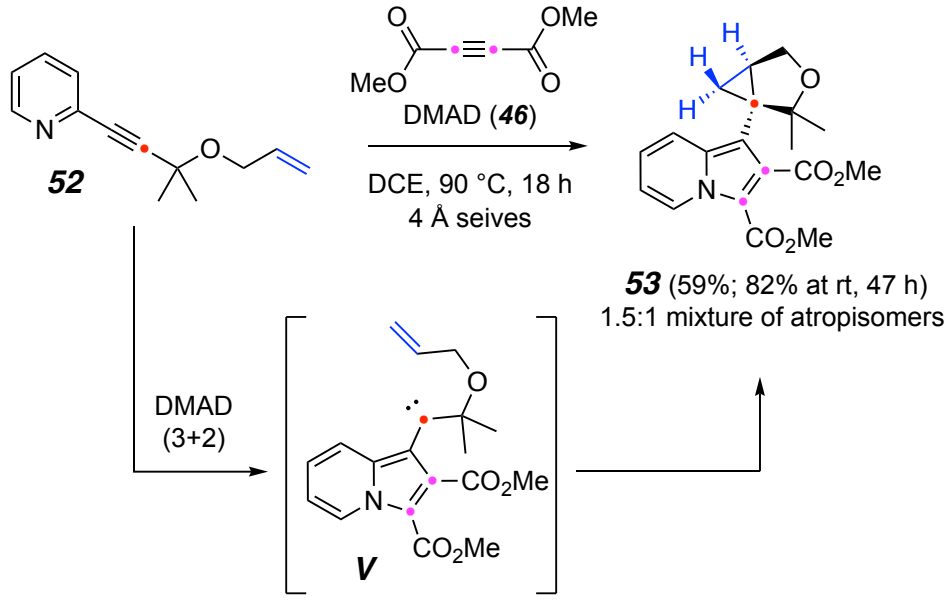


Figure 28. Intramolecular cyclopropanation of the tethered alkene substrate **52** to afford the cyclopropane **53**.

Upon accessing the ^{1}H NMR spectrum of cyclopropane **53**, we noted that there were two sets of proton resonances in a 1.5:1 ratio (Figure 29). Due to the close proximity of the indolizine to the sterically encumbered *gem*-dimethylated carbocycle, the indolizinyl cyclopropane bond is slow to rotate on the NMR timescale. Thus, spectroscopically, the material appears as two distinct atropisomers. Chromatographic separation of the two atropisomers was unable to be achieved, likely due to relatively fast interconversion on the "laboratory time-scale".

The positioning of the *gem*-dimethyl group also played a role in simplifying the product distribution. C–H bonds adjacent to carbenes may undergo 1,2-C–H insertions to furnish alkene products (cf. **56**, Figure 30).[68] In addition to this practical consideration, the *gem*-dimethyl functionality is a sought-after motif in drug discovery. *gem*-Dimethyl groups have been shown to impart desirable physicochemical and biological properties of biologically active compounds by virtue of reduced conformational flexibility and favorable van der Waals interactions.[74]

[74] Talele, T. T. Natural-products-inspired use of the *gem*-dimethyl group in medicinal chemistry. *J. Med. Chem.* **2018**, *61*, 2166–2210.

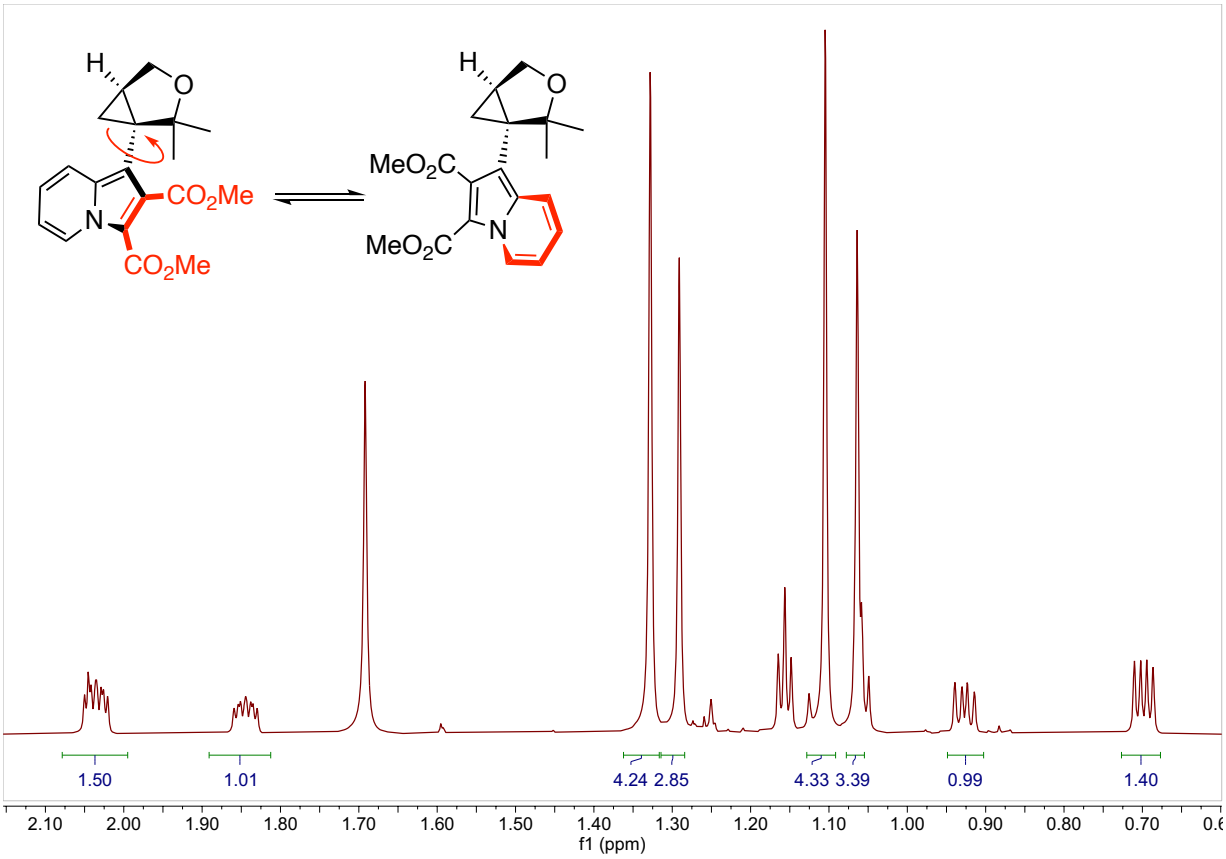


Figure 29. ^{1}H NMR of cyclopropane **53** showing a 1.5:1 ratio of interconverting atropisomers.

Next, we sought to probe whether the intramolecular cyclopropanation was stereospecific. In order to assess stereospecificity, we prepared the two geometric isomers, **54-*E*** and **54-*Z*,** and subjected the diastereomeric substrates to the same cyclopropanation conditions (Figure 30; note that the indolizine core is abbreviated as a grey ball in several of the product structures). The *trans* alkene derivative **54-*E*** led to the *trans*-configured cyclopropane **55** (48%) as the only observed cyclopropane product. Additionally, two alkene products, **56-*E,E*** (5%) and **56-*Z,E*** (35%), were isolated, arising from 1,2-C–H insertion of the free carbene **W** (Figure 30a). Conversely, the *cis* alkene derivative **54-*Z*** produced the all *cis*-configured cyclopropane **57** (39%) in addition to 1,2-C–H insertion products **56-*E,Z*** (5%) and **56-*Z,Z*** (35%) (Figure 30b). Because the alkene geometry of **54-*E*** and **54-*Z*** is fully translated to the respective cyclopropane products, the cyclopropanation is indeed stereospecific. It is noteworthy here to mention that the two enol ether 1,2-C–H insertion products isolated from both reactions were observed to isomerize when dissolved in $CDCl_3$ (a

mildly acid environment). Geometrically pure enol ethers are known to isomerize under acid catalyzed conditions via the intermediacy of oxocarbenium intermediates.[75]

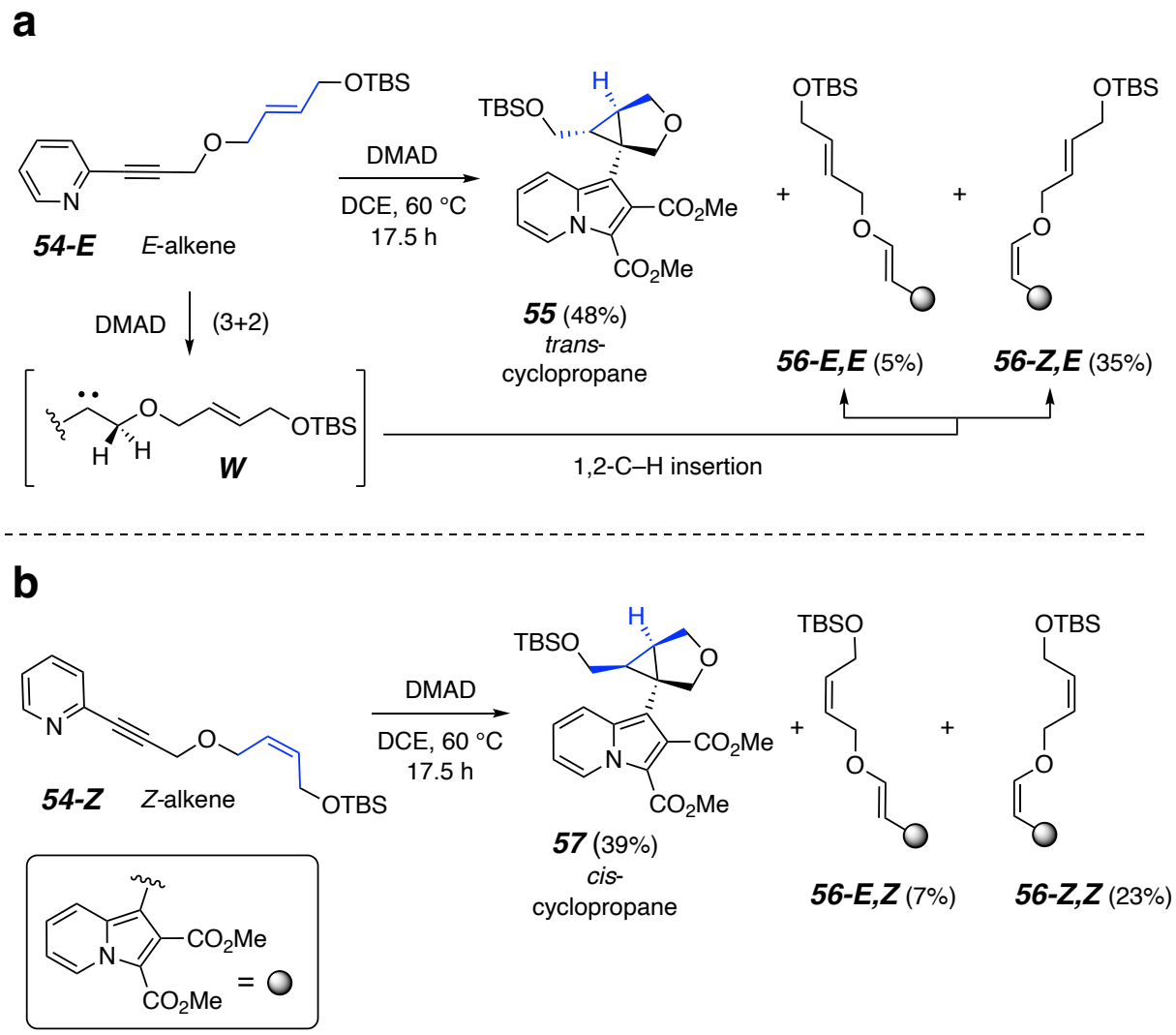


Figure 30. Stereospecific cyclopropanation of diastereomeric alkene derivatives (a) **54-*E*** and (b) **54-*Z***.

For most of these new cyclopropanations, we purposely chose to hold constant the DMAD (**46**) and 2-alkynylpyridine scaffold as the substrate pair to better focus attention on potential variations in efficiency associated with the nature of the tethering and the alkene on the remote terminus of the 2-alkynylpyridine (see **58a-i**, Figure 31). When each of these pyridine derivatives was warmed in a 1,2-dichloroethane (DCE) solution, it gave rise to the corresponding indolizine-

[75] Ahmad, S. A. Z.; Jena, T. K.; Khan, F. A. Alkyl enol ethers: Development in intermolecular organic Ttansformation. *Chem. Asian.* **2021**, *16*, 1685–1702.

containing product **59a-i** as the only isolated product, formed in generally good yield. Substrates **58a-e** are all based on a gem-dimethylated[74] ether linkage connecting the alkynyl pyridine to its tethered alkene. The degree of substitution on an unactivated alkene does not appreciably change the outcome (**53** vs. **59a**). Both 5- and 6-membered oxasilacycles were formed with similar efficiency (**59b** vs. **59c**). The heteroaromatic "alkenes" in the furan **58d** and the indole **58e** both engaged the carbene, producing **59d** and **59e**, although the latter in more modest yield compared with all of the other reactions of **58a-i**. Several additional substrates containing other types of tethers were shown to be effective. The *N*-diallyl amide **58f** reacted somewhat more slowly than any of the other pyridines, likely a reflection of slightly reduced nucleophilicity of the pyridine nitrogen atom (see later discussion), but still proceeded smoothly. Substrates **58g-i** whose tethers contain embedded aryl groups behaved well, leading to benzofuran (**59g** and **59i**) or benzopyran (**59h**) derivatives. Both **59g** and **59h** were isolated as single diastereomers, corroborating the stereospecific nature of the cyclopropanation event. When cyclohexeneone **59i** was initially heated in the presence of DMAD at 90 °C, only baseline decomposition was observed by TLC analysis. In recognizing the potential fragmentation issues associated with the thermally labile push-pull cyclopropane system in the product **59i**, we elected to run the experiment at room temperature. At reduced temperature, the hindered cyclopropane product **59i** (88% combined yield) could be isolated as a pair of diastereomeric atropisomers. Heating each diastereomeric atropisomer individually resulted in slow degradation but gave no sign of their interconversion. Nearly all of the other products **59a-h** showed atropisomerism in their NMR spectra but were indistinguishable on the "chromatographic timescale."

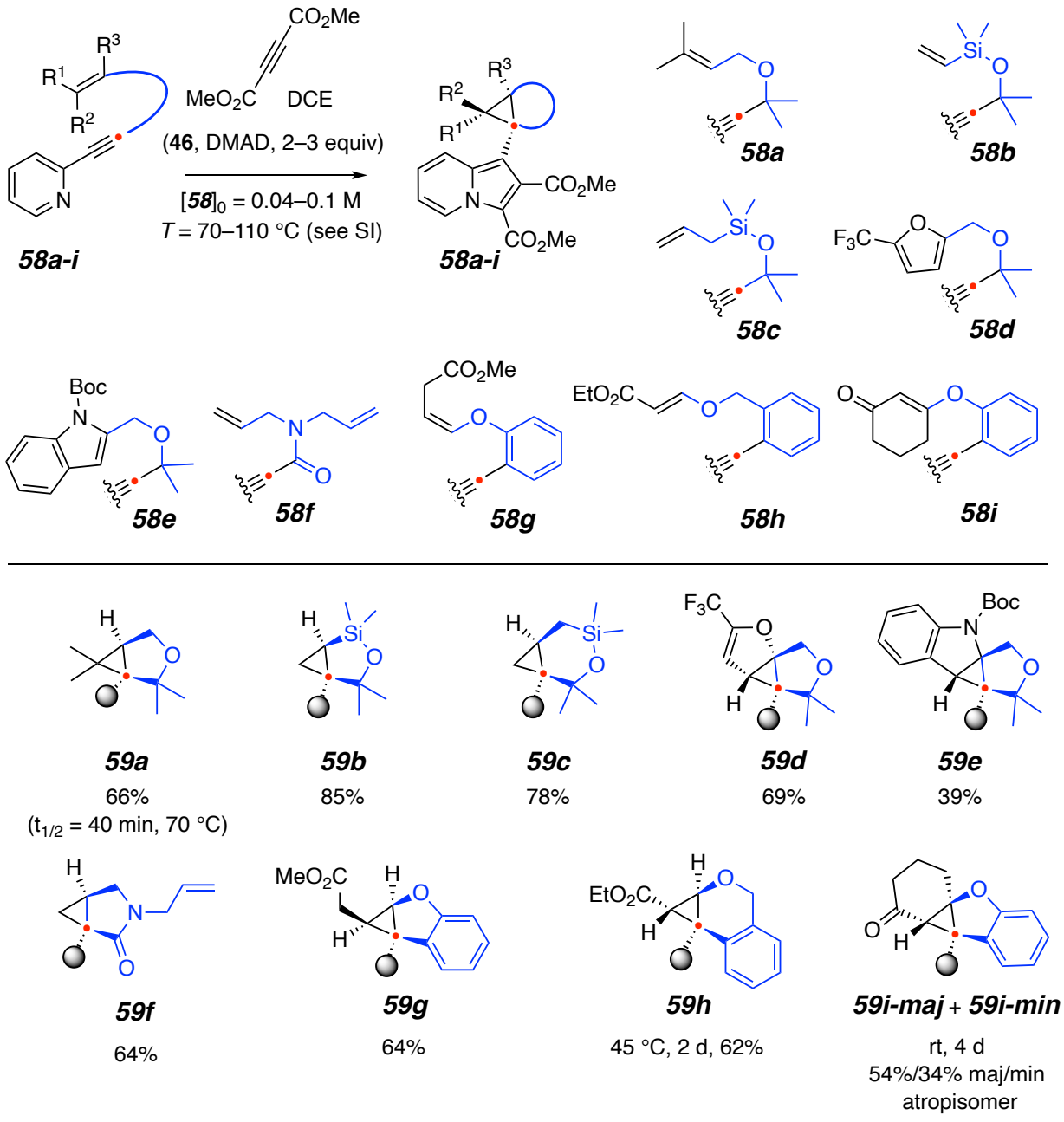
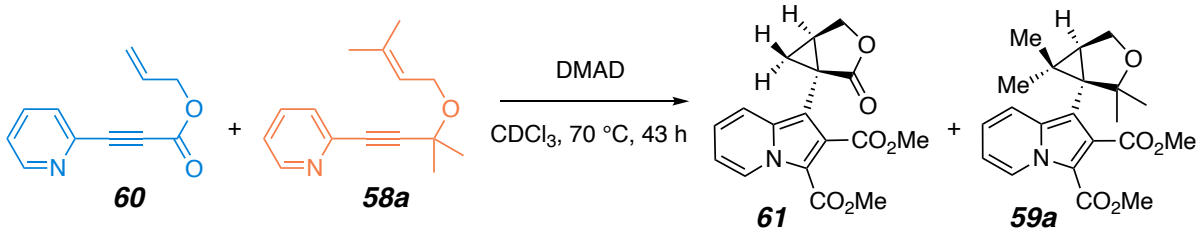


Figure 31. 2-Alkylypyridines containing tethered alkenes (**58a–i**) reacting with DMAD to produce a series of structurally diverse fused cyclopropanes **59a–i**.

In order probe how substrate modifications may influence the overall rate of reaction, we compared the relative half-life of the *gem*-dimethyl alkynyl pyridine **58a** to the allyl ynoate **60**. Allyl ynoate **60** was predicted to react more slowly than **58a** because the electron withdrawing nature of the carbonyl functionality reduces the nucleophilicity of the pyridine nitrogen. The

relative rates of **60** and **58a** could be tracked simultaneously by an ^{1}H NMR experiment in which both **60** and **58a** were dissolved in the same NMR tube and heated to 70 °C in the presence of excess of DMAD over the course of 43 h. Percent conversion was determined by tracking characteristic NMR integrations of the two precursors and comparing them to the residual $CHCl_3$ resonance, which served as an internal standard. The relative half-life of **60** was estimated to be 15 h @ 70 °C, and the relative half-life of **58a** is estimated to be 40 min @ 70 °C. This experiment suggests that the nucleophilicity of the 2-alkynyl iminoheterocycle significantly influences the overall rate of reaction.



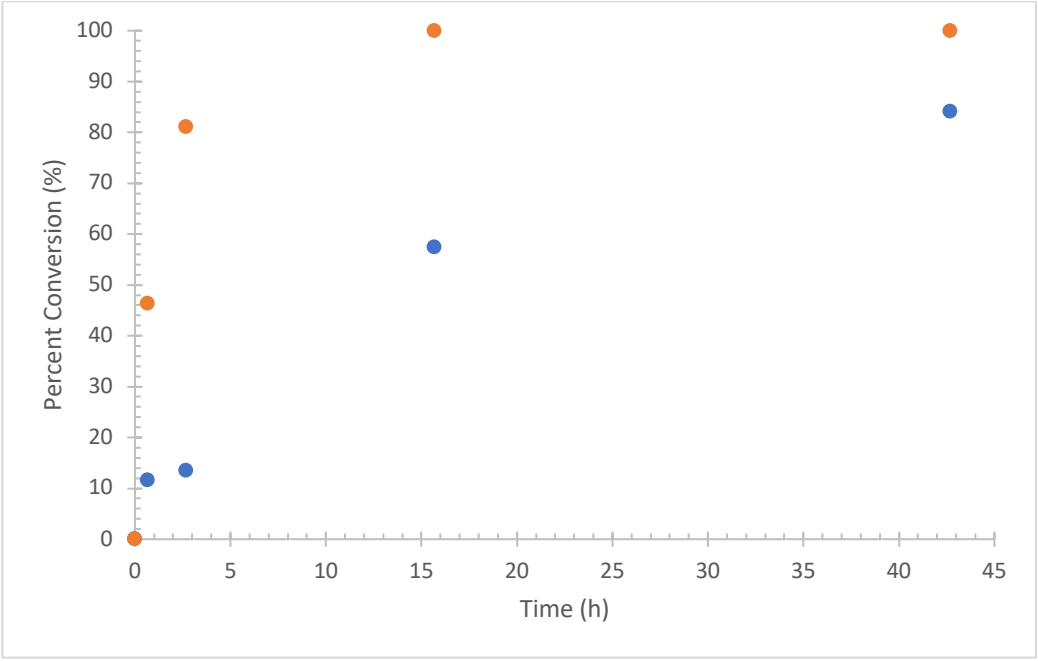


Figure 32. Percent conversion of 60 and of 58a as a function of reaction time.

The cyclopropanation reaction is by no means limited to pyridine derivatives or to DMAD (Xu showed[68] that 13 different types of iminoheterocycles **R** and 11 different types of electrophilic alkynes **S** participated in the generic carbene forming reaction shown in Figure 26). Other 2-alkynyl iminoheterocycles are demonstrated here by derivatives of a thiazole (**62**), an *N*-methylbenzimidazole (**64**), a quinoline (**66**), and a pyridazine (**68**) (Figure 33). Each participated

in the overall cyclopropanation process in good to excellent yields (Figure 33). The thiazole, quinoline, and pyridazine precursors reacted more slowly, likely a reflection of reduced nucleophilicity of the heterocyclic nitrogen atom.

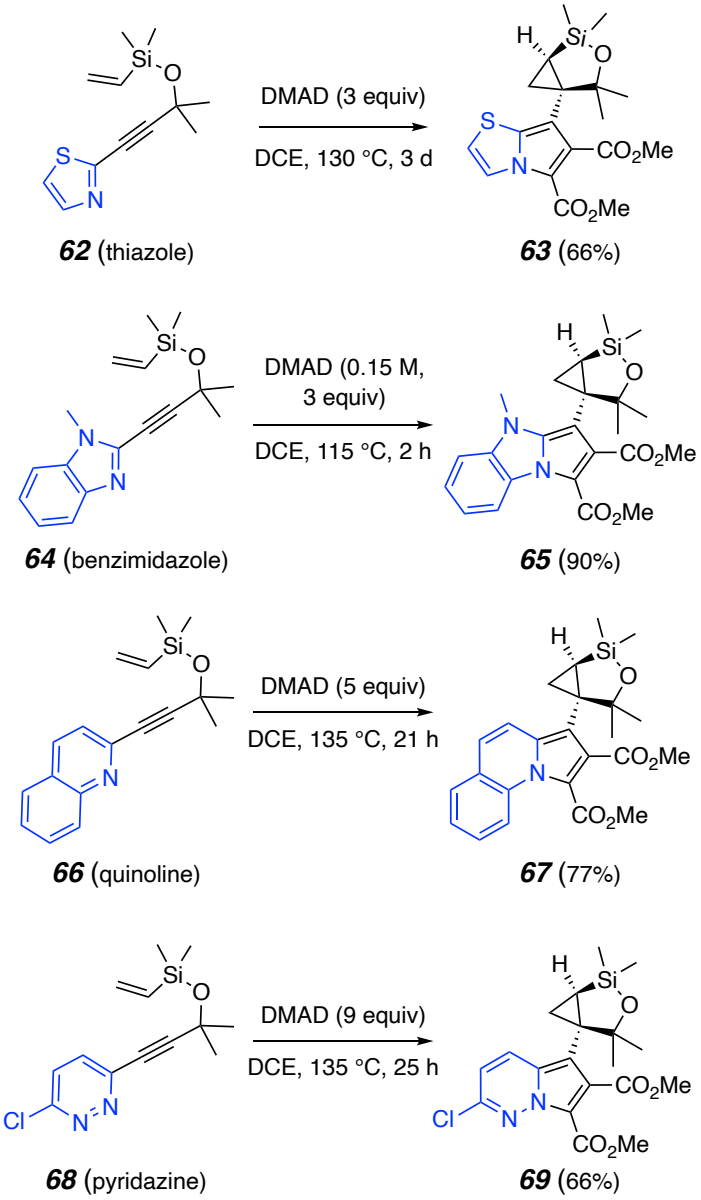


Figure 33. Cyclopropanation reactions involving other iminoheterocycles.

The full ^{1}H NMR and partial ^{13}C NMR assignment of the cyclopropane **63** was a particularly challenging task for two reasons: (a) excessive broadening, a result of slow heteroaryl-cyclopropane bond rotation, erased valuable coupling constant information, and (b) we observed an unusual long-range HMBC correlation. The issue of problematic resonance broadening was

solved by taking the ^{1}H NMR spectrum at 110 °C in DMSO-d_6, which revealed three distinct cyclopropane resonances with resolved coupling constants (Figure 34). A model compound, acetate **71**, was synthesized in order to support the posited pyrrolo[2,1-*b*]thiazole substructure of cyclopropane **63** (Figure 35). The reliable acetate migration "reporter group" developed by Xu[68] was employed for this purpose, and the alkenyl acetate **71** (67%) was formed cleanly. We observed the analogous long-range HMBC (from the *H2* proton to the *C6* carbon), suggesting that both the cyclopropane **63** and the alkenyl acetate **71** contain a pyrrolo[2,1-*b*]thiazole core.

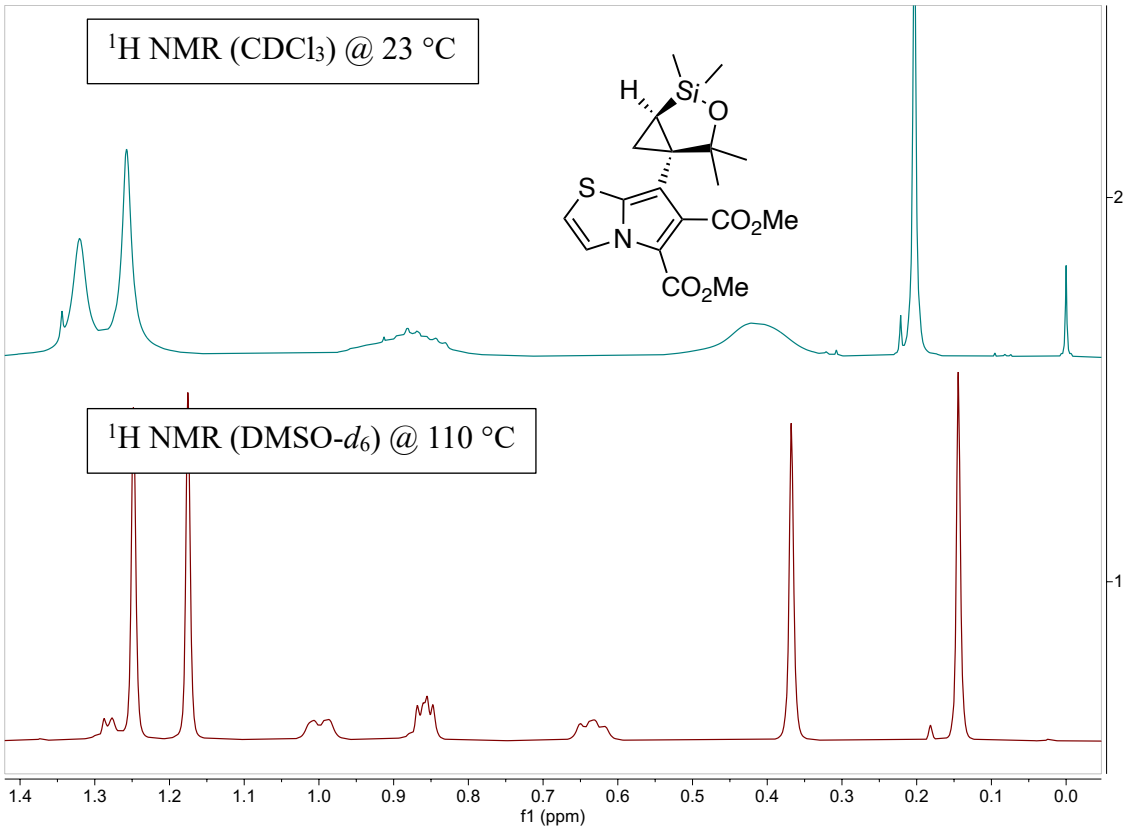


Figure 34. ^{1}H NMR spectra of **63** taken at 23 °C (CDCl$_3$) and at 110 °C (DMSO-d_6).

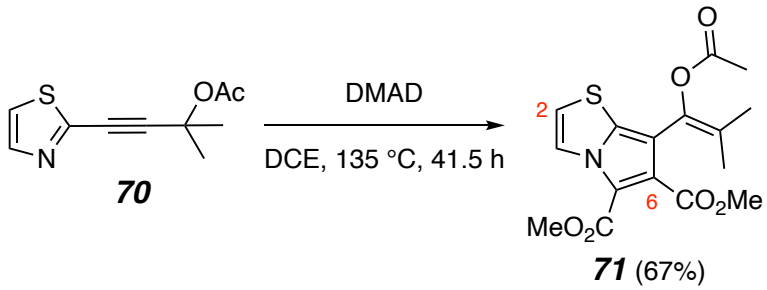


Figure 35. Employing acetate reporter group for the formation of model compound **71**.

We also showed that DMAD was not required as the electrophilic alkyne partner (Figure 36). When heated under similar conditions to the analogous reaction using DMAD, **58f** reacted with the trifluorobutynoate **72** to afford the trifluoromethyl functionalized indolizine cyclopropane product **73** (62%). *o*-Benzynes are also electron-deficient alkynes; therefore, we hypothesized that when heated in the presence of allyl ynoate **60**, the hexadehydro-Diels–Alder (HDDA) precursor **23** would initiate a HDDA/formal (3+2)/cyclopropanation cascade. Through the intermediacy of HDDA benzyne **G**, triyne **23** could in fact be converted to the cyclopropane product **74** (36%).

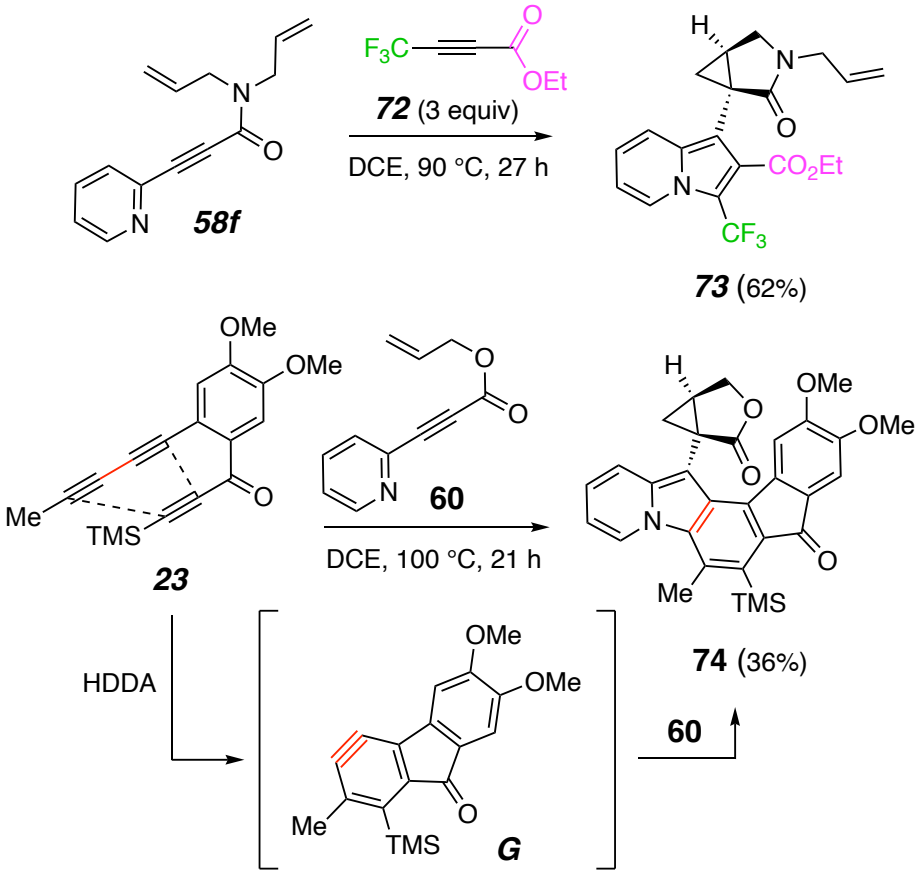


Figure 36. Cyclopropanation reactions involving non-DMAD electron-deficient alkynes.

In several cases, we observed side products resulting from reactions of the free carbene intermediates that compete with intramolecular cyclopropanation. One instance involved the conversion of diynyl pyridine **75**, the enthynylog of **58b**, to the alkyne substituted cyclopropane **76** (76%) (Figure 37). The reaction proceeds via a propynylidene intermediate **X**, which has carbene character at its internal and external positions, allowing for cyclopropanation to occur at the dotted carbon (highlighted in red). Propynylidene intermediates are species that have rarely

been utilized in synthetic settings; rather, these intermediates have traditionally been studied for their spectroscopic properties and fundamental reactivity.[76] Along with the major cyclopropane product, a small amount of a 2:1 adduct **77** (3%) was formed (Xu had reported on an analogous process[68]). The propynylidene intermediate was competitively intercepted by the proximal methyl ester to form 1,3-dipole **Y**. A second equivalent of DAMD then participated in a (3+2) cycloaddition with **Y** to arrive at oxabicycle **Z**. Electron density from the neighboring enamine subunit of the indolizine assists in the elimination of the bridging oxygen, which led to zwitterionic intermediate **AA**. Ultimately, the zwitterion is quenched by a 1,2-methoxy shift to afford the 2:1 adduct **77**.

Two substrates with an ester embedded within the alkene tether were examined. Each demonstrated a type of reaction process that competes with the cyclopropanation. The acrylate **78** (Figure 38a) was used to probe whether an electron-deficient alkene would engage the carbene. However, a faster [2,3]-sigmatropic rearrangement of the carbene[68] **AB** occurred instead, giving **79** as the only product isolated following purification of the reaction mixture. The allyl ynoate **60** (Figure 38b), like the amide substrate **58f**, has an electron-withdrawing group directly bound to the alkyne terminus. Like **58f**, it reacted somewhat more slowly than most of the other substrates ($t_{1/2}$ ca. 15 h for **60** vs. 40 min for **58a**, both at 70 °C, Figure 32). Presumably the reduced nucleophilicity of the pyridine nitrogen atom in **60** (or **58f**) slows the rate of engagement of a DMAD molecule. The ynoate **60** gave the cyclopropane **61** as the predominant product, but this was accompanied by a small amount of the unusual 2:1 adduct **80**. Assigning the structure of this unexpected side product was initially perplexing until we learned that allylic-allylic, 5-bond couplings (both *trans* and *cis*) in 1,4-cyclohexadiene (and, presumably, its derivatives) is surprisingly large: 8.0 and 9.6 Hz, respectively.[77] The allylic methine proton in **80** shows coupling

[76] Seburg, R. A.; DePinto, J. T.; Patterson, E. V.; McMahon, R. J. Structure of triplet propynylidene. *J. Am. Chem. Soc.* **1995**, *117*, 835–836.
[77] E. W. Garbisch; M. G. Griffith. The conformation of 1,4-cyclohexadiene from stereoisomeric allylic-allylic proton couplings. *J. Am. Chem. Soc.* **1968**, *90*, 3590–3592.

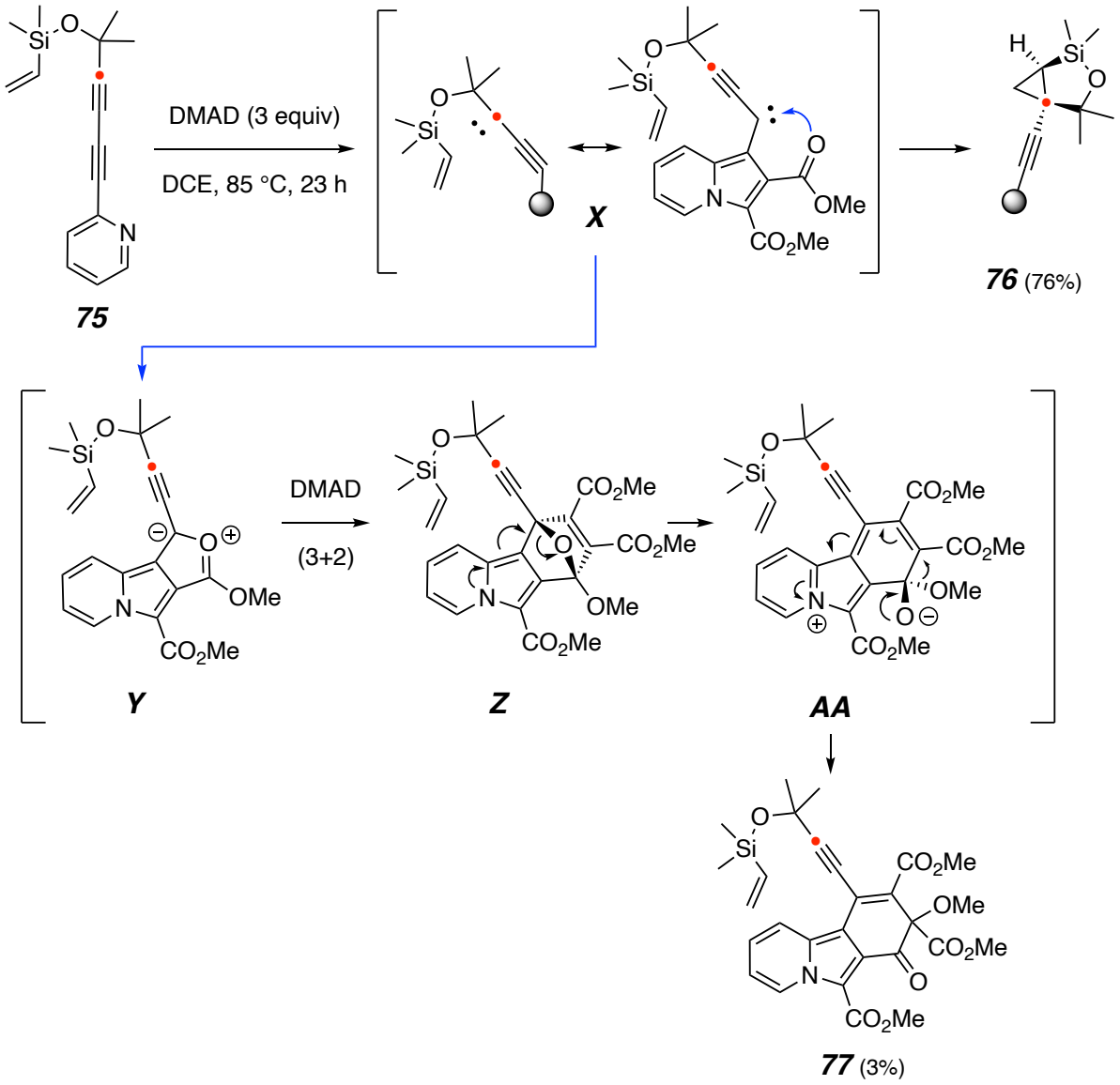


Figure 37. Cyclopropanation reaction involving a diyne (ethynylog) precursor.

to each of the remote methylene protons of 8.3 Hz, and the 1,4-cyclohexadiene subunit accounts for the very large observed geminal coupling constant of 23.5 Hz. Formation of this side product can be rationalized by a C–H insertion event within the carbene **AC** that is competitive with the cyclopropanation. The resulting β-lactone **AD** can then eject carbon dioxide giving the diene **AE**, whose [4+2] Diels-Alder reaction with a second molecule of DMAD accounts for formation of **80**.

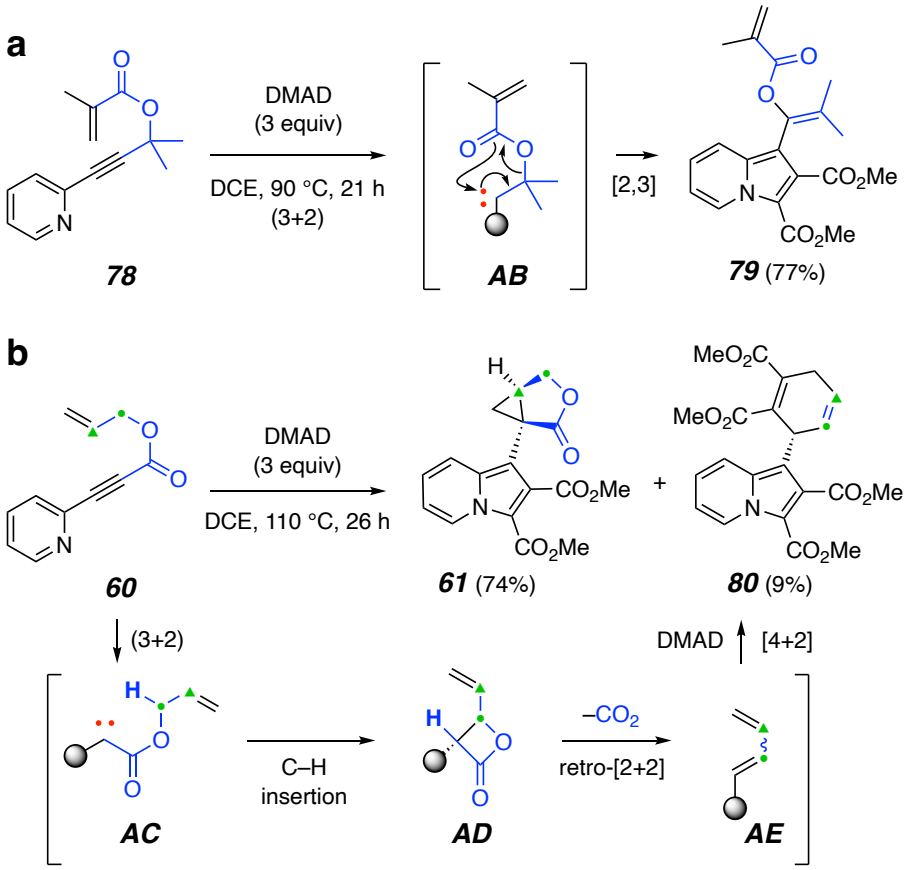


Figure 38. Substrates reacting to give non-cyclopropane-containing products arising from: **a)** 1,2-ester migration and **b)** an intramolecular C–H insertion leading to the minor product **80**, which has incorporated two equivalents of DMAD and lost CO_2.

The concentration of DMAD can influence the rate of events that compete with carbene formation. For example, the benzimidazole **64**, in the presence of a higher concentration of DMAD (0.5 vs. 0.15 M in the Figure 33 vs. 39 reactions), formed predominately the previously unobserved 2:1 adduct **81** (77%) in addition to the (now) minor cyclopropane product **65** (23%). The zwitterionic intermediate **AF** may proceed to a carbene intermediate via a 5-*exo-dig* cyclization or engage a second equivalent of DMAD in a formal (4+2) cycloaddition to generate **81**. Similar transformations of benzimidazoles have previously been reported.[78]

[78] Foxton, M. W.; Road, P. Addition reactions of heterocyclic compounds. Part XXVI.* Dimethyl acetyienedicarboxylate with imidazoles and benzimidazoles. *J. Chem. Soc. C,* **1967**, 882–887.

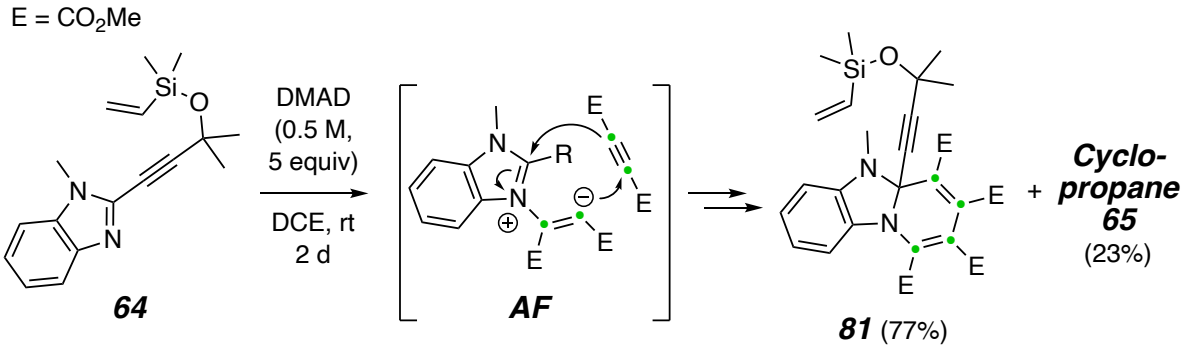


Figure 39. Competition between carbene formation and cycloaddition of zwitterionic intermediate **AF** with DMAD to generate the 2:1 adduct **81**.

The furan-containing precursor **82** was designed to further explore aspects of dearomative cyclopropanations (Figure 40). This ynone substrate required heating at 60 °C for several days to reach high conversion. Instead of a cyclopropane-containing product, we isolated the pair of enal geometric isomers **83-*Z*** (54%) and **83-*E*** (4%). Wenkert and co-workers had reported similar reactivity using rhodium carbenoid complexes of substrates bearing pendant furans.[79] They suggested that cyclopropane intermediates were not formed; rather, that the purported metallacyclic intermediates cleaved to generate the enal products. We propose here that the free carbene *does* cyclopropanate the tethered furan (cf. **59d**, Figure 31) to produce, now, the transient species **AG**. However, this intermediate, a donor-acceptor (push-pull) activated cyclopropane,[80] is susceptible to facile ring-opening and readily proceeds under the thermal reaction conditions to the fragmentated dienal **83-*Z*** either in a concerted fashion or, perhaps, via the intermediate zwitterion **AH**. We also observed that the *cis*-enal isomer **83-*Z*** readily photoisomerizes in ambient light to the more thermodynamically stable *trans*-enal **83-*E***, a phenomenon that Wenkert and co-workers also had seen. In order to probe whether the isomerization was indeed photoinduced, a purified sample of **83-*Z*** was divided into two NMR tubes. One of the samples was exposed to ambient light conditions, while the other sample was wrapped in tin foil and placed in a dark

[79] Wenkert, E.; Guo, M.; Pizzo, F.; Ramachandran, K. Synthesis of 2-cycloalkenones (parts of 1,4-diacyl-1,3-butadiene systems) and of a heterocyclic analogue by metal-catalyzed decomposition of 2-diazoacylfurans. *Helv. Chim. Acta* **1987**, *70*, 1429–1438.

[80] (a) For a related reaction of an isolable (benzo)furan-derived cyclopropane, see: Fuerst, D. E.; Stoltz, B. M.; Wood, J. L. Synthesis of C(3) benzofuran-derived bisaryl quaternary centers: Approaches to diazonamide A. *Org. Lett.* **2000**, *2*, 3521–3523. (b) For a recent review of donor-acceptor cyclopropane reactivity, see: Xia, Y.; Liu, X.; Feng, X. Asymmetric catalytic reactions of donor–acceptor cyclopropanes. *Angew. Chem. Int. Ed.* **2021**, *60*, 9192–9204 and citations therein to numerous earlier reviews.

environment. By tracking the rate of isomerization of the two samples, we concluded that the isomerization was photoinduced.

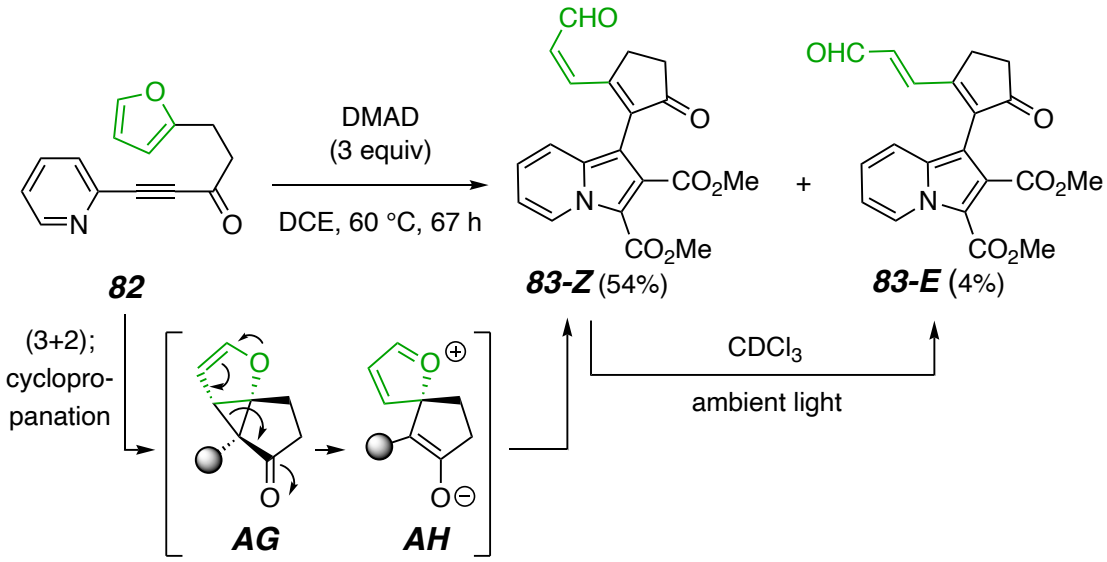


Figure 40. Furan fragmentation and rearrangement arising from labile donor-acceptor cyclopropanes intermediate. (gray ball = the 2,3-dicarbomethoxy-1-indolizinyl moiety)

The vinylogous ester **84** was prepared next to examine whether a tetrasubstituted and highly polarized alkene would participate in the cyclopropanation reaction (Figure 41). When the reaction with DMAD was carried out at room temperature, the fully substituted, hindered cyclopropane **85** was isolated as two, chromatographically separable atropisomers in a 70% combined yield. Additionally, a minor amount of the isomeric benzopyran derivatives **86** was isolated (10% and 7%), again as a separable pair of atropisomers. When the major isomer of the cyclopropane, **85-maj**, was heated at 80 °C for 47 h in $CDCl_3$, it fully transformed to the same 10:7 equilibrium ratio of **86-maj**:**86-min**. The **85-min** at the same temperature also converted to the same ratio of products **86**, albeit more slowly than its diastereomer, **85-maj**. Thus, the cyclopropane is indeed an intermediate enroute to **86**. To account for this conversion, the cleavage of the strained ring in either of the atropisomeric push-pull cyclopropanes is accompanied by loss of benzenoid aromatic character. The spirocyclic zwitterion **AI** can then ring-open to the ortho-quinone methide derivative **AJ**, now a common intermediate from either of the precursors **85-maj** or **85-min**. A final 6π electrocyclization step generates **86**.

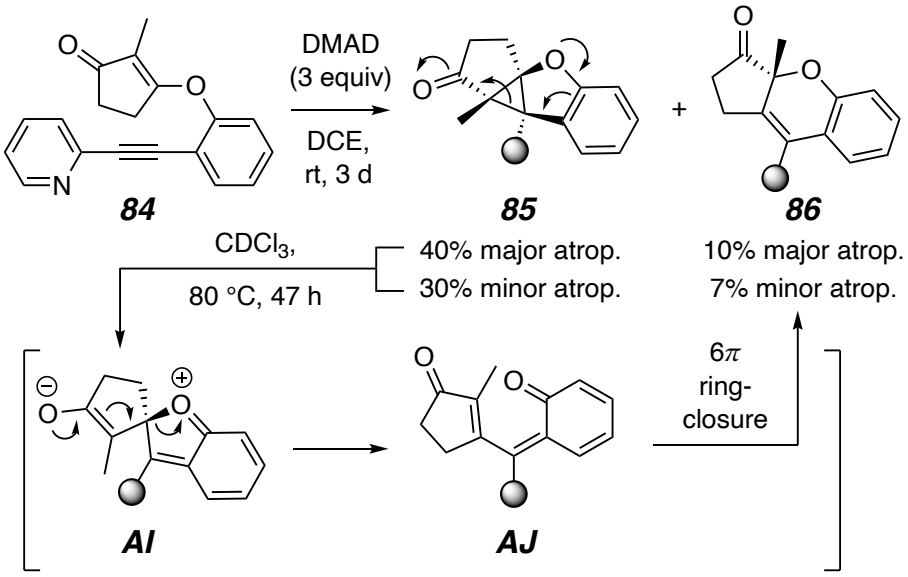


Figure 41. Donor-acceptor cyclopropane proceeding to fragmentation products.

We demonstrated a formal *inter*molecular cyclopropanation by disassembling the tether between the carbene and engaging alkene: namely, desilylation of the siloxane **59b** (Figure 42). Treatment with TBAF afforded alcohol **87** (94%), a process that included desilylation of the cyclopropane ring.[81] Alternatively, the cyclopropane ring could be derivatized to the corresponding cyclopropanol **88** under Fleming–Tamao oxidation conditions in excellent yield (98%).

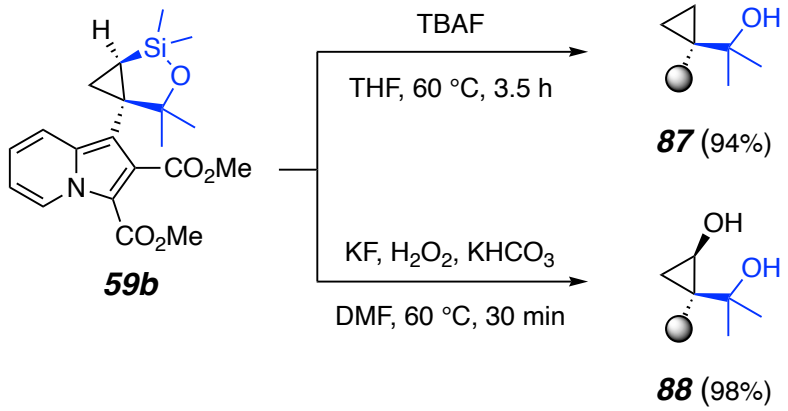


Figure 42. Silicon-containing tether removal via **a**) net protodesilylation or **b**) Fleming-Tamao oxidative cleavage to produce a cyclopropane or cyclopropanol derivative.

[81] E.g., Paquette, L. A.; Yan, T. H.; Wells, G. J. Silicon in organic synthesis. 25. Thermolysis and desiliconation-alkylation of [1-(trimethylsilyl)cyclopropyl]ethylenes as a route to spirocyclic sesquiterpenes. *J. Org. Chem.* **1984**, *49*, 3610–3617.

3.5 Conclusion

In conclusion, a series of multicyclic, fused-ring cyclopropane derivatives has been synthesized via the capture of intermediate free carbenes by pendant alkenes. Various 2-alkynyl iminoheterocycles engage electron-deficient alkynes to produce the transient carbenes that undergo the intramolecular cyclopropanation. Notably, the metal-free carbenes and the derived cyclopropane products retain all of the atoms of the reactants and arise simply by combining reactivity-matched pairs of shelf-stable alkyne substrates; the high potential energy of those alkynes fuels the formation of the reactive carbene intermediate. A 2-(1,3-diynyl)pyridine substrate bestowed carbenic reactivity at the more remote alkyne to produce an alkynyl cyclopropane via a propynylidene. Furan and indole dearomatizations were demonstrated. In some instances, further fragmentation products derived from labile donor-acceptor cyclopropane species were observed. A removable siloxane tether could be excised to achieve formal *inter*molecular cyclopropanations and the synthesis of cyclopropanol derivatives.

Chapter IV: Heteroaryl-stabilized, (Free) Carbene-enabled, 3-Component Reactions

The following chapter reflects work in collaboration with Katharine B. Toll.

4.1 Introduction

Free carbenes and their metal-bound carbenoid counterparts have enabled synthetic methodology through a diverse display of reactivity: e.g, cyclopropanation, ylide generation, and X-H/C-H insertion.[56,57,71] Diazo compounds can be employed as free carbene precursors, which eject molecular nitrogen under thermal[56] or photochemical conditions[57] (Figure 24). Davies and co-workers pioneered the broad application of intermolecular trapping of free carbenes to allow for rapid construction of highly functionalized and complex products.[82] However, the intermolecular trapping reactions of heteroaryl-substituted free carbenes is underexplored and underutilized.[66]

We recently described the formal (3+2) cycloaddition between 2-alkynyl iminoheterocycles and electron-deficient alkynes to afford heteroaryl free carbene intermediates (Figure 26).[68] In addition to the reactivity displayed by free carbenes in the initial report (including, but not limited to, C–H insertion, (3,2)-sigmatropic rearrangement, 1,3-dipole formation, and carbene metathesis), we have demonstrated the ability to access complex polycyclic cyclopropanes via intramolecular capture of the carbene by tethered alkenes.[83] In exploring the reactivity of various electron-deficient alkynes, we observed an unexpected product **90** (34%) when reacting the allyl ether **52** with the terminal conjugated 1-yne-3-one derivative **89** (Figure 43). This unexpected product had incorporated two equivalents of ynone **89**, one producing the carbene intermediate **AK** and a second incorporated through a formal C–H insertion event of the carbenic carbon atom into the terminal alkyne C–H bond of **89**. This can be rationalized via a deprotonation–ion pair collapse (see intermediates **AK** to **AL**, Figure 43), a process precedented by work of

[82] (a) Hansen, S. R.; Spangler, J. E.; Hansen, J. H.; Davies, H. M. L. Metal-free N–H insertions of donor/acceptor carbenes. *Org. Lett.* **2012**, *14*, 4626–4629. (b) Jurberg, I. D.; Davies, H. M. L. Blue light-promoted photolysis of aryldiazoacetates. *Chem. Sci.* **2018**, *9*, 5112–5118.

[83] Guzman, A. L.; Mann, A. N.; Hoye, T. R. Alkynes to (free) carbenes to polycyclic cyclopropanes. *J. Am. Chem. Soc.* **2024**, *146*, 28642–28647.

Koenigs and coworkers for the capture of a different class of free carbene by a terminal alkyne.[84] The formation of **90** led us to initiate a study of additional examples in which various types of a third component might efficiently trap heteroaryl-substituted carbenes. We report here on the results of these investigations of three-component reactions, which provide structurally interesting heterocyclic products in a single operation.

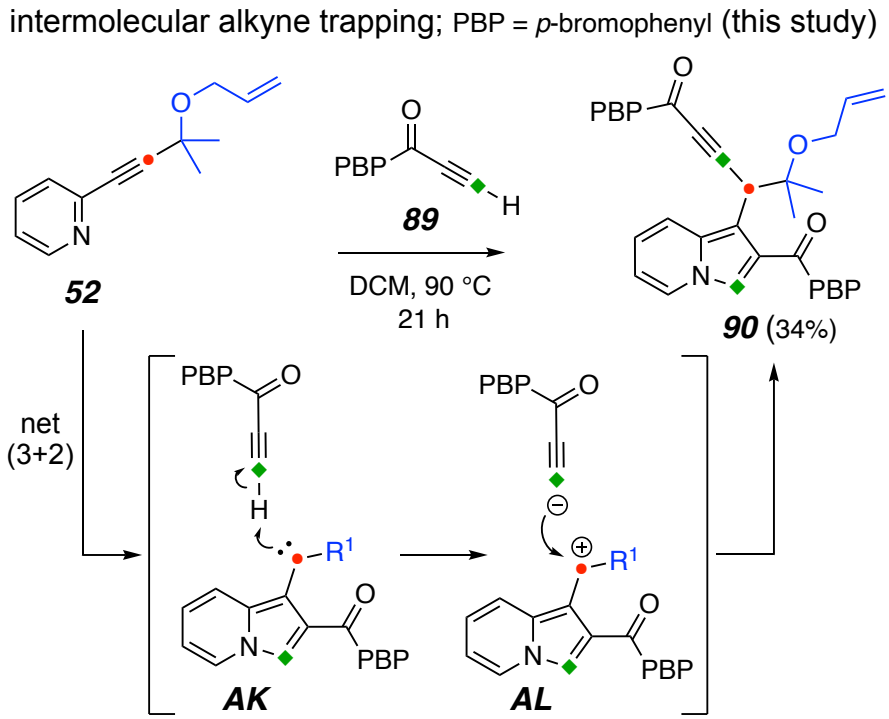


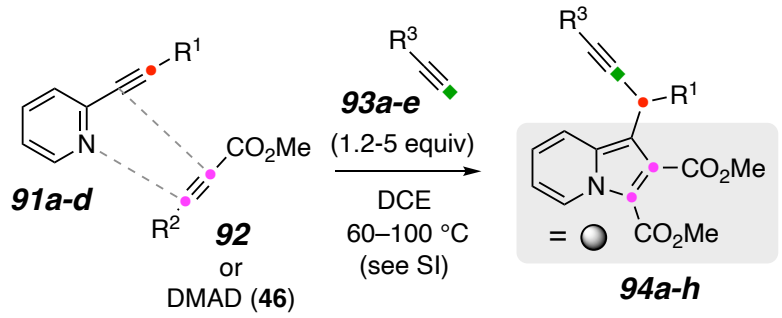
Figure 43. Unexpected intramolecular trapping of free carbene **AK** with terminal alkyne **89**.

4.2 Results and Discussion

Additional examples of three-component reactions involving trapping by a terminal alkyne are shown in Figure 44. Product **90** (cf. Figure 43) had incorporated two equivalents of the ynone **89**, one functioning as the electrophilic alkyne and the second to trap the carbene **AK**. Another example of this is seen in products **94a/b** in which two copies of methyl propiolate (**92**), another electrophilic terminal alkyne, have been engaged. We recognized that the versatility of this three-component process would be increased if three different molecules could be integrated into the products. We set out to achieve this outcome by using two different types of alkynes, one to

[84] Jana, S.; Pei, C.; Empel, C.; Koenigs, R. M. Photochemical carbene transfer reactions of aryl/aryl diazoalkanes—experiment and theory. *Angew. Chem. Int. Ed.* **2021**, *60*, 13271–13279.

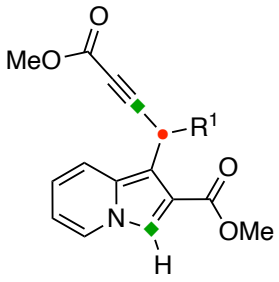
function as the electrophilic moiety to drive carbene formation and the second, a terminal alkyne, to capture the carbene.



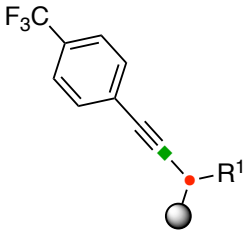
91	R^1
a	PMP[a]
b	cyclopropyl
c	1-MeO-cyclohexyl
d	3-azetidinyl

	R^2
92	H
46	CO_2Me

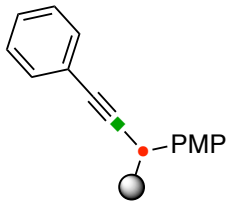
93	R^3
a	*p*-$F_3CC_6H_4$
b	Ph
c	3-pyridyl
d	Ph(Me)NC=O
e	*N*-Boc-indolyl



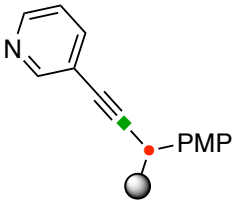
94a/b
a R^1 = PMP, 50%
b R^1 = cyclopropyl, 52%



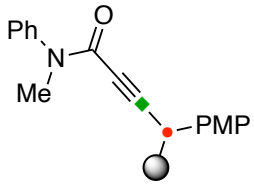
94c/d
c R^1 = PMP, 43%
d R^1 = 1-methoxycyclohexyl, 42%



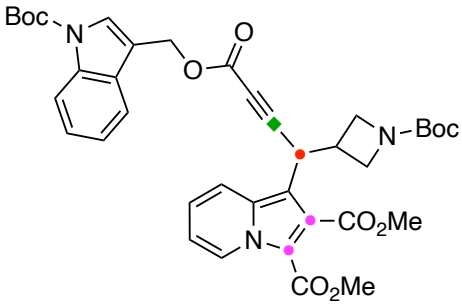
94e (57%)
phenylacetylene cosolvent



94f (41%)



94g
trap equiv:
1.2 (62%), 1.75 (73%), 5.0 (84%)



94h (61%)

Figure 44. Third component trapping of free carbenes derived from alkynylpyridines **91a-d** with terminal alkynes **93a-e**.

In the presence of dimethyl acetylenedicarboxylate (**46**, DMAD), the alkynylpyridine **91a**, and 1-ethynyl-4-(trifluoromethyl)benzene (**93a**), could be transformed to the corresponding trapped product **94c** (43%). The majority of these experiments utilized DMAD as the electron deficient alkyne because DMAD, unlike electron-deficient terminal alkynes, is unable to participate in C–H insertion chemistry. There were no cases in which the third component trap outcompeted DMAD in the formation of indolizinyl carbenes. The formation of the 1-methoxycyclohexane derivative **94d** (42%) shows that a bulky quaternized alkyl substituent on the terminus of the alkynylpyridine is tolerated. Phenylacetylene (**93b**) trapped the carbene to form **94e**. However, this least acidic of the terminal alkynes **93a-e** required the use of a large excess of **93b** (1:1 cosolvent) to achieve the yield of 57%, implying that it is relatively slow at engaging the electron rich carbene. 3-Ethynylpyridine (**93c**) was sufficiently electron-poor to participate as the trapping component to generate **94f** (41%). The highest yielding alkyne trap was *N*-methyl-*N*-phenylpropiolamide (**93d**), leading to the amide derivative **94g** (84%). We varied the loading of **93d** from 1.2 to 5.0 equivalents and observed increasing yields at higher trap loadings (1.2 equiv; 62%, 1.75 equiv; 73%, and 5.0 equiv; 84%).

Finally, we were interested in whether a propiolate derivative trap would compete with the more electrophilic DMAD to produce the carbene. Using the indole-containing propiolate derivative **93e** (along with the azetidinylated alkyne **91d**), we observed the formation of **94h** in 61% yield. It is notable that the methine hydrogen atom at C3 of the azetidine (vicinal to the carbene) did not interfere by way of a 1,2-insertion event into the initially propargylic C–H bond, a process that earlier was shown to be efficient (i.e., fast) for carbenes containing simple alkyl substituents.[68] The ring strain associated with the formation of an exo-alkylidene azetidine apparently reduces the rate of this intramolecular process. Notice that a similar factor was relevant to the compatibility of the cyclopropane ring during the formation of **94b** described earlier.

In exploring a broader scope of functional groups that would serve as the carbene trapping agent (i.e., the third-component), we found that *N*-Boc-carbamates were effective. This discovery greatly expanded the opportunities and utility of this methodology, given the large pool of valuable and commercially available amine-containing coupling partners. The results of carbamate trapping are shown in Figure 45; DMAD was held constant as the electrophilic alkyne partner.

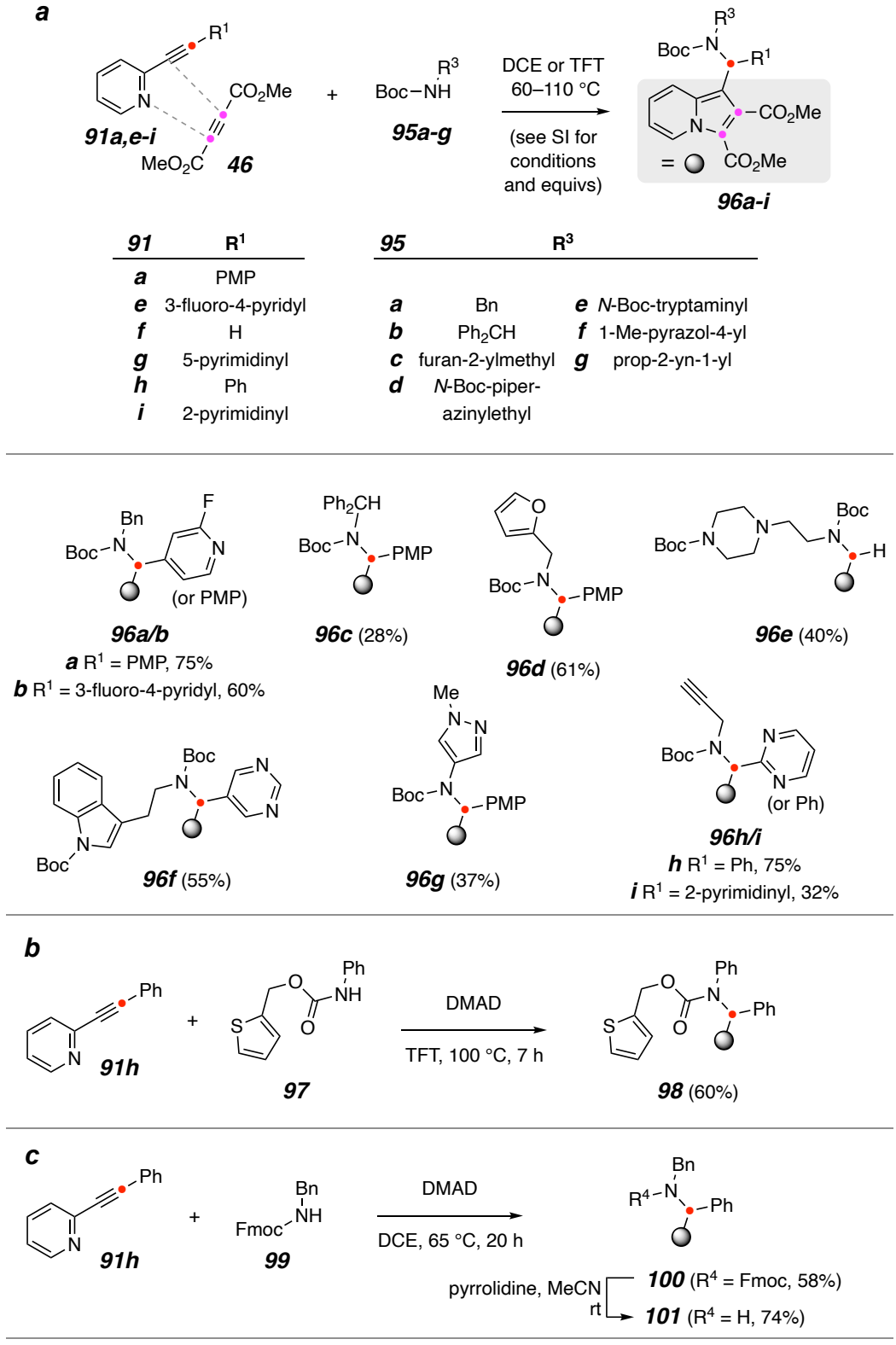


Figure 45. Third component trapping of (a) *N*-Boc-carbamates, (b) thiophen-2-ylmethyl phenylcarbamate (**97**), and (c) *N*-Fmoc-benzylamine (**99**).

N-Boc-benzylamine (**95a**) trapped the carbene to provide **96a** (75%). Use of a 3-fluoro-4-pyridyl substrate **91e** led to **96b** (60%). The trapping with *N*-Boc-diphenylmethanamine (**95b**) to give **96c** proceeded with lower efficiency (28%), showing that the steric bulk of the BocNH compound can be a limitation. An array of heterocycle-containing traps is tolerated: *N*-Boc-furfurylamine (**95c**) gave **96d** (61%); the piperazine derivative **95d** gave **96e** (40%); the indole derivative **95e** gave **96f** (55%); and the amino pyrazole derivative **95f** gave **96g** (37%). *N*-Boc-Propargylamine (**95g**) in principle could have inserted at either its N–H or terminal alkyne C–H bond; we only observed products of NH trapping: **96h** (75%) and **96i** (32%), perhaps a function of the relative acidity of the two potential sites of reaction.

We sought to further capitalize on the carbamate substitution as a handle to append heterocycle functionality. Accordingly, the thiophen-2-ylmethyl carbamate **97** was found to trap efficiently, leading to adduct **98** (60%, Figure 45b). Attempts to deprotect several of the *N*-Boc-carbamate products described in Figure 45a under typical conditions (TFA/chloroform, rt) showed surprisingly complex behavior. In the deprotection experiments involving PMP substrates, we were able to identify *p*-methoxybenzaldehyde as a common degradation side product.

This prompted us to examine the Fmoc-carbamate **99**, which gave **100** (58%, Figure 45c). In contrast to Boc-removal attempts under acidic conditions, this product could be smoothly deprotected to the secondary amine **101** when exposed to pyrrolidine in acetonitrile.

We also found that amide and urea derivatives behaved well in the three-component reaction (Figure 46). The secondary amide, *N*-methylbenzamide, was a particularly effective trap leading to **102** (86%). The primary acetamide also participated to give **103** (54%). An azepine-5-carboxamide derivative was used to establish that a urea would engage the carbene, here to produce **104** (62%).

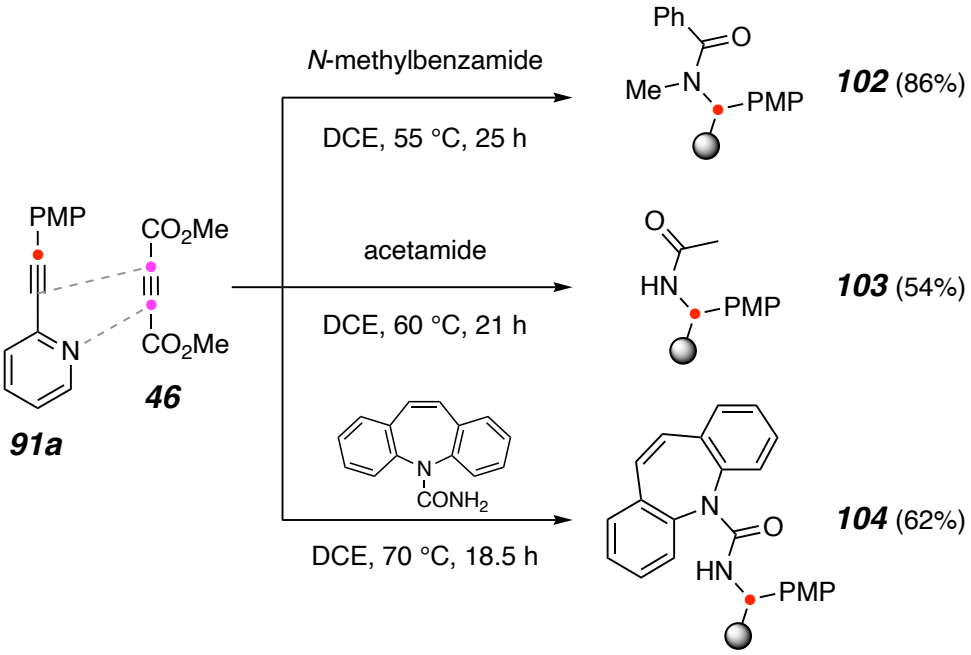


Figure 46. Amides and a urea trapping of the carbene produced from the alkynylpyridine **91a** and DMAD (**46**).

Iminoheterocycles other than pyridine have been shown to be effective carbene precursors.[68] Here we used *N*-Boc-carbamates to establish the effectiveness of several different heterocycles in this three-component approach (Figure 47). The 2-alkynylthiazole **105** was trapped with *N*-Boc-benzylamine (**95a**), *N*-Boc-aniline (**95h**), and the *N*-Boc-valine derivative **95i** to give **106** (76%), **107** (70%), and **108** (55%), respectively. The valine adduct **108** was formed as a 1.1:1.0 mixture of coeluting diastereomers, suggesting that it is unlikely that a substantial degree of stereoselectivity could be found in these NH insertion reactions. In comparison to its pyridine analogue **91a**, the thiazole substrate **105** requires higher temperatures to achieve full conversion. Results from Xu's mechanistic DFT analysis[68] suggest that the rate-determining process is generation of the free carbene. The rate-determining elementary step could change as the alkynyliminoheterocycle and the electron-deficient alkyne reaction partners are varied, but the third component trap has no influence on the overall reaction rate. The pyrimidine substrate **109** was even slower to react, although it still afforded the product **110** in respectable yield (54%). Lastly, we studied a non-aromatic iminoheterocycle, the dihydropyrrole derivative **111**. Although this substrate generated the carbene more quickly, it proved to be less efficient in producing the three-component trapped product **112** (34%).

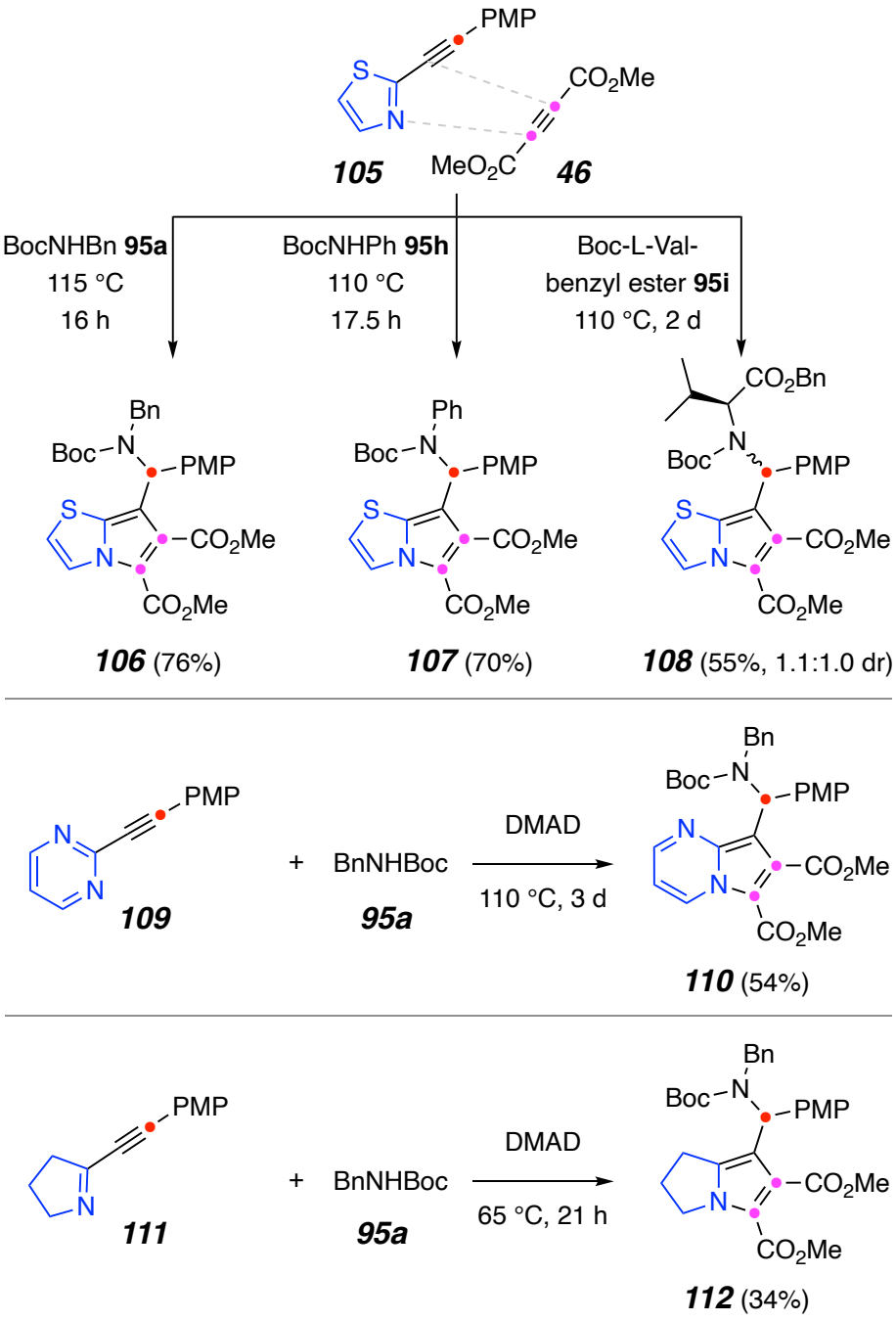


Figure 47. Alkynyl iminoheterocycles other than pyridine (thiazole **105**, pyrimidine **109**, and dihydropyrrole **111**) can also participate in the three-component coupling.

We surveyed several other carbon species to explore whether we could identify any net C–H insertion events analogous to the alkynylations described in Figure 44. Modestly acidic carbon acids were selected. Somewhat surprisingly, we were unsuccessful in attempts to use any of cyclopentane-1,3-dione, dimethyl malonate, or malononitrile to achieve this reaction. An

exception was the use of chloroform, a reactant that has been studied in some detail for its ability to engage *N*-heterocyclic carbenes (NHCs) through net CH insertion.[85] Indeed the chloroform adduct **113-H** was isolated in 74% yield when **91a** and DMAD were reacted in $CHCl_3$ at 100 °C. When this reaction was performed in a 14:1 volume ratio of $CDCl_3$:$CHCl_3$, the isotopomers **113-H** and **113-D** were formed in a 54:46 ratio, indicative of a substantial isotope effect (ca. k_H/k_D ~16) and cleavage of the C–H bond in the product-determining step. This, however, does not differentiate between a concerted or stepwise (via the ion pair **AM**) process for interception of the free carbene. This mechanistic distinction in the earlier reaction of NHCs with chloroform also remained an open question based on the experimental work,[85a] although a DFT analysis[85b] favored an ion pair pathway. Treating the chloroform adduct **113-H** with $^nBuNH_2$ led to the clean formation of the elimination product, dichloroalkene **114** (97%).

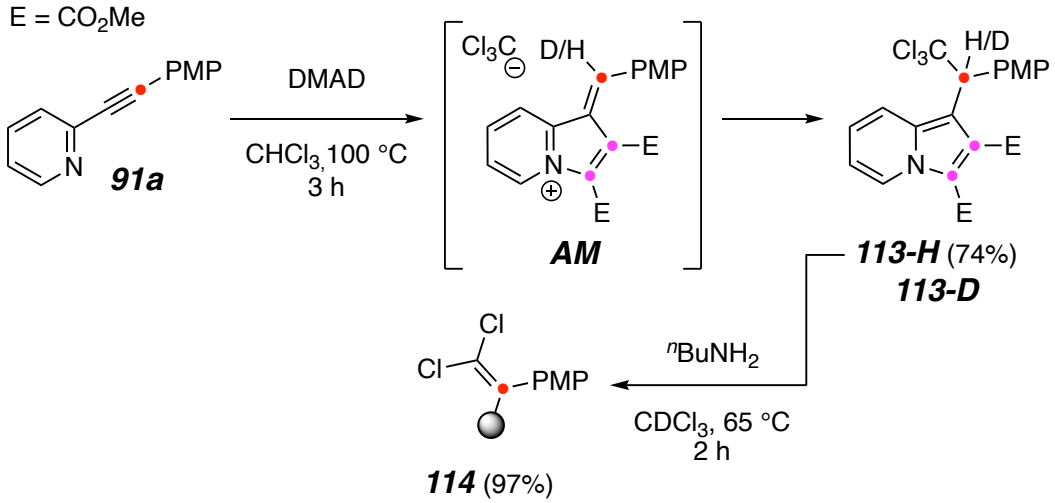


Figure 48. Formal carbene insertion into the C–H bond of $CHCl_3$.

Presented in Figure 49 are several additional examples of reactions that hint at some additional diversity in the types of products that can be accessed. Electron-deficient alkyne partners other than DMAD can be used. The trifluoromethyl diynyl ketone **115** reacted with the alkynylpyridine **91h** and *N*-Boc-benzylamine (**95a**) to afford the alkynyl-substituted indolizine **116**

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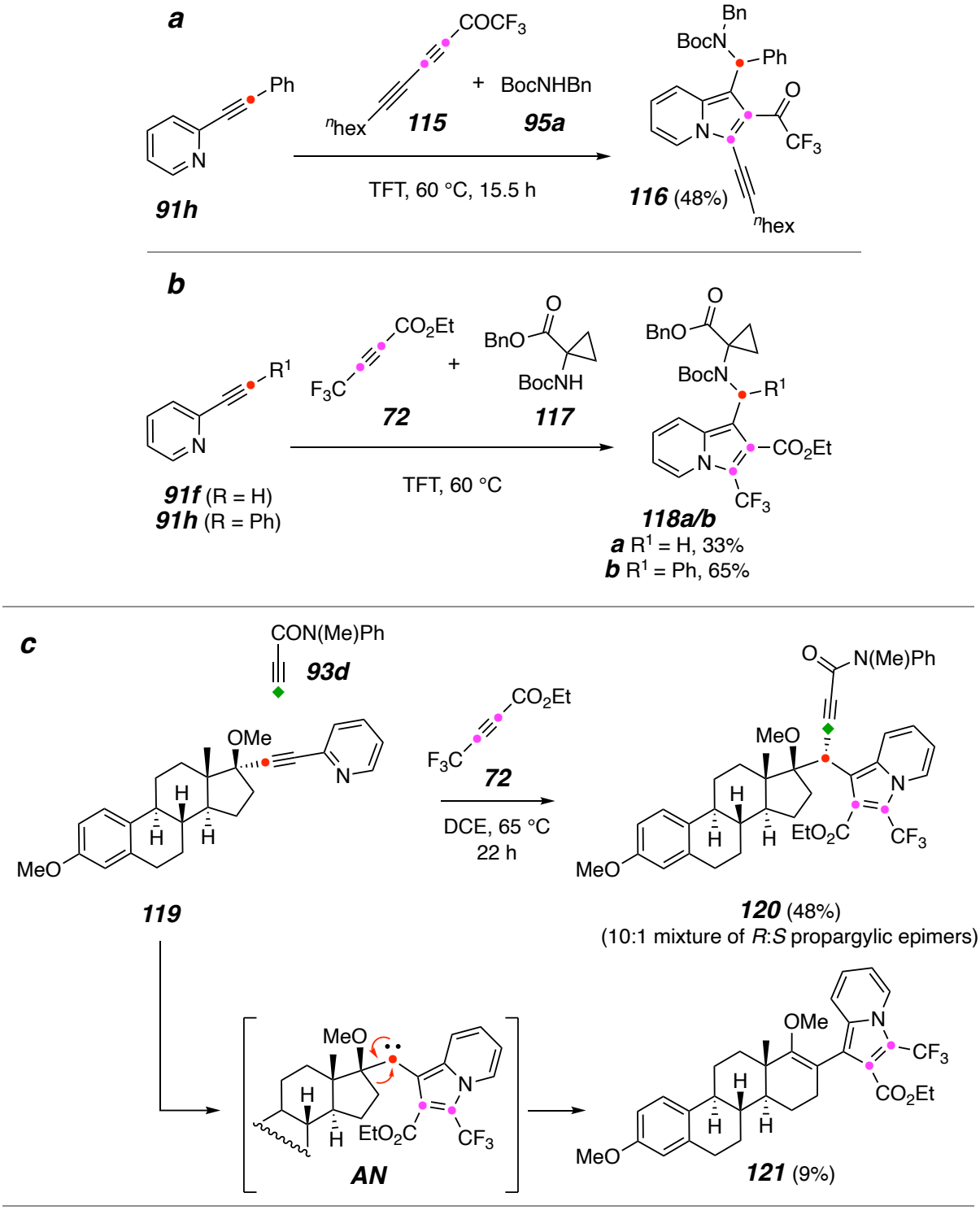

Figure 49. Electron-deficient alkyne partners other than DMAD participating in three-component coupling reactions.

(48%) as a single regioisomer (Figure 49a). The alkynylpyridine derivatives **91f** and **91h** engaged trifluorobutynoate **72** and the *N*-Boc-cyclopropylamine **117**, respectively, to produce the trifluoromethyl substituted indolizine **118a** (33%) and **118b** (65%), respectively (Figure 49b). Comparison of the outcomes of 2-ethynylpyridine (**91f**) vs. its phenyl-substituted analogue **91h** reveals that the terminal alkyne substrate is, overall, a less efficient participant in the 3-component reaction (cf. also the marginal yield of product **96e**, Figure 45).

We wanted to probe whether the three-component reaction could be applied in the context of an even more complex molecular setting. We prepared the estradiol derivative **119**, to which a requisite alkynyl iminoheterocycle functionality has been appended (Figure 49c). When heated in the presence of the trifluorobutynoate **72** and *N*-methyl-*N*-phenylpropiolamide (**93d**), the steroidyl alkynylpyridine **119** was converted into the indolizine derivative **120** (48%) as a 10:1 coeluting mixture of epimers at the newly created (propargylic) stereogenic center. (A DP4+ analysis suggested that the major epimer has the *R* configuration; see SI section II). The level of diastereoselectivity (relative asymmetric induction) in this transformation is notable, as is the formation of small amount of the cyclic enol ether **121** (9%), presumably arising from the ring-expansion/rearrangement indicated in the carbene **AN**.[86]

4.3 Conclusion

In conclusion, we have demonstrated that free carbenes generated by the formal (3+2) cycloaddition between 2-alkynyliminoheterocycles and electron-deficient alkynes can trap a variety of third components. Electron-deficient terminal alkynes and secondary *N*-Boc carbamates, amides, and ureas are all functionalities capable of participating in third component trapping. It is perhaps relevant that the pKa's of the CH or NH are similar across this series of effective third components. Each of the three reaction partners – the alkynyliminoheterocycle, the electron-deficient alkyne, and the carbene trapping agent – can be varied, demonstrating the potential for formation of a diverse collection of poly-heteroaromatic products. Indolizine derivatives **94h** (Figure 44) and **96f** (Figure 45) are notable examples of products with a high degree of heterocycle incorporation.

[86] E.g., Padwa, A.; Austin, D. J.; Gareau, Y.; Kassir, J. M.; Xu, S. L. Rearrangement of alkynyl and vinyl carbenoids via the rhodium(ii)-catalyzed cyclization reaction of α-diazo ketones. *J. Am. Chem. Soc.* **1993**, *115*, 2637–2647.

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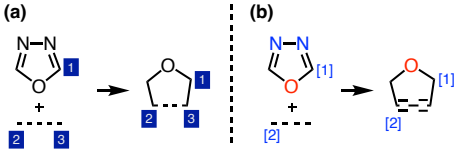

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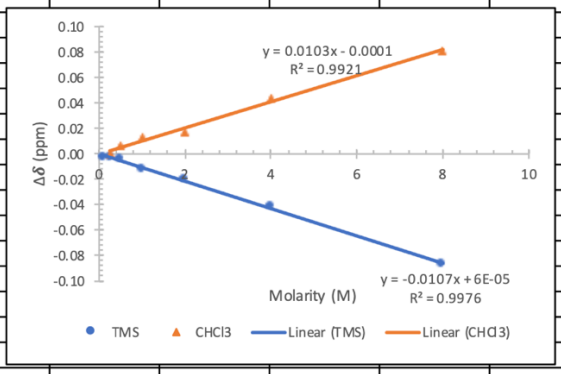
Supplementary Information for Chapter I

General Experimental Protocols

External solute samples were prepared by serial dilutions, starting with relatively high concentrated stock solutions (1–8 M, depending on the molecular volume of the solute) of the solute of interest dissolved in $CDCl_3$ (99.8% D) containing 0.05% TMS. Each external solute sample was then placed into a 5 mm WILMAD 535-PP (PREC 600 MHz) NMR tube. A New Era Enterprises capillary (NE-262-2) was filled with a solution of $CDCl_3$ (99.8% D) containing 0.05% TMS (i.e., the "standard"), capped with a New Era Enterprises Teflon® capillary adapter (NE-325-5/2.5), and carefully inserted into the 5 mm NMR tube (assisted by a NE-341-5 support rod) containing the external solute solution. All NMR spectra were recorded on a Bruker Avance III HD AX-400 instrument (400 MHz). At the outset, the performance of this concentric tube arrangement was checked by using the same, standard solution in both the internal capillary compartment and the outer annulus tube. This produced a spectrum with only a single observable resonance for each of the TMS and residual $CHCl_3$ protons (as well as for the trace of water impurity).

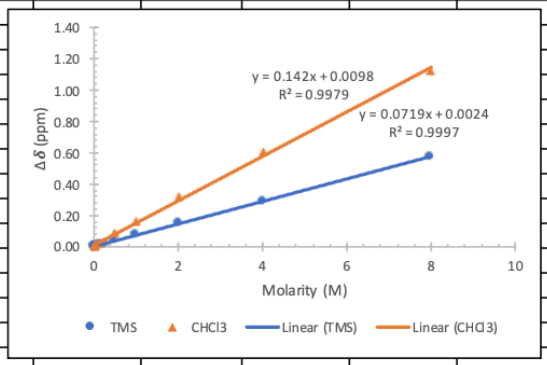
1-Fluoro-4-Nitrobenzene

Molarity		δTMS (ppm)	δCHCl3 (ppm)		Molarity (M)	ΔδTMS (ppr	ΔδCHCl3 (ppm)		
8M	Internal	0	7.26		8	-0.087	N/A		
	External	-0.087	Hidden/overlapped		4	-0.041	0.081		
	Δ	-0.087	N/A		2	-0.02	0.044		
					1	-0.012	0.017		
					0.5	-0.004	0.013		
4M	Internal	0	7.259		0.25	-0.003	0.006		
	External	-0.041	7.34		0.125	-0.003	0		
	Δ	-0.041	0.081						
2M	Internal	0	7.259						
	External	-0.02	7.303						
	Δ	-0.02	0.044						
1M	Internal	0	7.263						
	External	-0.012	7.28						
	Δ	-0.012	0.017						
0.5M	Internal	0	7.26						
	External	-0.004	7.273						
	Δ	-0.004	0.013						
0.25M	Internal	0	7.26						
	External	-0.003	7.266						
	Δ	-0.003	0.006						
0.125M	Internal	0	7.261						
	External	-0.003	7.261						
	Δ	-0.003	0						



Acetone

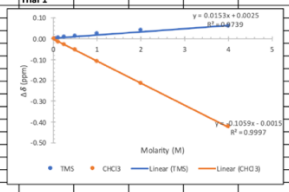
Molarity		δTMS (ppm)	δCHCl3 (ppm)		Molarity (M)	ΔδTMS (pp	ΔδCHCl3 (ppm)		
8M	Internal	0	7.26		8	0.575	1.123		
	External	0.575	8.383		4	0.292	0.608		
	Δ	0.575	1.123		2	0.151	0.318		
					1	0.078	0.164		
					0.5	0.04	0.084		
4M	Internal	0	7.26		0.25	0.017	0.036		
	External	0.292	7.868		0.125	0.009	0.019		
	Δ	0.292	0.608		0.0625	0.008	0.014		
					0.03125	0.002	0.006		
					0.015625	0.004	0.005		
2M	Internal	0	7.26		0.0078125	0	0.001		
	External	0.151	7.578						
	Δ	0.151	0.318						
1M	Internal	0	7.26						
	External	0.078	7.424						
	Δ	0.078	0.164						
0.5M	Internal	0	7.26						
	External	0.04	7.344						
	Δ	0.04	0.084						
0.25M	Internal	0	7.26						
	External	0.017	7.296						
	Δ	0.017	0.036						
0.125M	Internal	0	7.26						
	External	0.009	7.279						
	Δ	0.009	0.019						
0.0625M	Internal	0	7.259						
	External	0.008	7.273						
	Δ	0.008	0.014						
0.03125M	Internal	0	7.259						
	External	0.002	7.265						
	Δ	0.002	0.006						
0.015625M	Internal	0	7.26						
	External	0.004	7.265						
	Δ	0.004	0.005						
0.0078M	Internal	0	7.26						
	External	0	7.261						
	Δ	0	0.001						

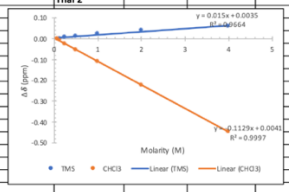


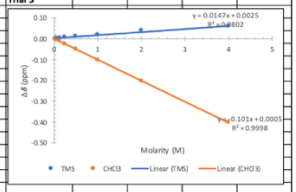
Benzene

Trial 1												
Molarity		δTMS (ppm)	δCHCl3 (ppm)			Trial 1	Trial 1	Trial 2	Trial 2	Trial 3	Trial 3
8M	Internal	0	Iden/overlapped		Molarity (M)	ΔδTMS (ppm)	ΔδCHCl3 (ppm)	ΔδTMS (ppm)	ΔδCHCl3 (ppm)	ΔδTMS (ppm)	ΔδCHCl3 (ppm)
	External	0.053	6.443		8	0.053	N/A	0.053	N/A	0.054	N/A
	Δ	0.053	N/A		4	0.06	-0.423	0.06	-0.446	0.058	-0.402
					2	0.039	-0.216	0.039	-0.223	0.037	-0.203
					1	0.021	-0.11	0.022	-0.11	0.02	-0.103
4M	Internal	0	7.26		0.5	0.011	-0.056	0.012	-0.055	0.011	-0.052
	External	0.06	6.837		0.25	0.006	-0.028	0.006	-0.027	0.006	-0.025
	Δ	0.06	-0.423		0.125	0.002	-0.016	0	-0.006	0.003	-0.01
					0.0625	0	-0.007	0	0	0.002	-0.006
					0.03125	0	0	0	0	0	0
2M	Internal	0	7.26		0.015625	0	-0.003	0	0	0.005	-0.022
	External	0.039	7.044		0.0078125	0	0	0	-0.004	0	0
	Δ	0.039	-0.216		0.00390625	0	0	0.004	-0.022	0	-0.004
1M	Internal	0	7.26								
	External	0.021	7.15								
	Δ	0.021	-0.11								

Trial 1	Trial 2	Trial 3
0.5M Internal 0 7.26		
External 0.011 7.204		
Δ 0.011 -0.056		
0.25M Internal 0 7.26		
External 0.006 7.232		
Δ 0.006 -0.028		
0.125M Internal 0 7.26		
External 0.002 7.244		
Δ 0.002 -0.016		







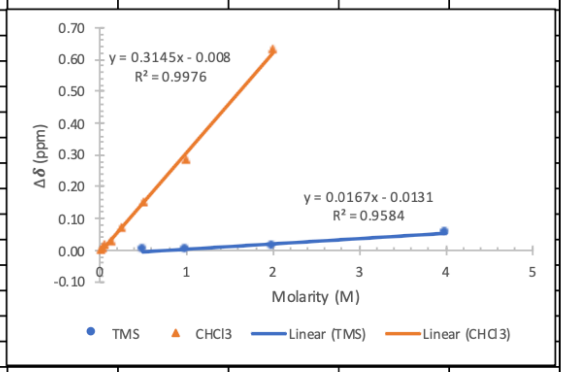
	CHCl3		TMS	
0.0625M Internal 0 7.259		Slope		Slope
External 0 7.252	Trail 1	-0.1059	Trail 1	0.0153
Δ 0 -0.007	Trail 2	-0.1129	Trail 2	0.015
	Trail 3	-0.101	Trail 3	0.0147
	Ave:	-0.1066	**Ave:**	0.015
0.03125M Internal 0 7.256	**SD:**	0.0059808	**SD:**	0.0003
External 0 7.256				
Δ 0 0				
0.015625M Internal 0 7.261				
External 0 7.258				
Δ 0 -0.003				
.0078125M Internal 0 7.259				
External 0 7.259				
Δ 0 0				
.00390625M Internal 0 7.26				
External 0 7.26				
Δ 0 0				

Benzene

Trail 2				
Molarity		δTMS (ppm)	δCHCl3 (ppm)	
8M	Internal	0	den/overlapped	
	External	0.053	6.451	
	Δ	0.053	N/A	
4M	Internal	0	7.26	
	External	0.06	6.814	
	Δ	0.06	-0.446	
2M	Internal	0	7.26	
	External	0.039	7.037	
	Δ	0.039	-0.223	
1M	Internal	0	7.26	
	External	0.022	7.15	
	Δ	0.022	-0.11	
0.5M	Internal	0	7.26	
	External	0.012	7.205	
	Δ	0.012	-0.055	
0.25M	Internal	0	7.259	
	External	0.006	7.232	
	Δ	0.006	-0.027	
0.125M	Internal	0	7.243	
	External	0	7.237	
	Δ	0	-0.006	
0.0625M	Internal	0	7.251	
	External	0	7.251	
	Δ	0	0	
0.03125M	Internal	0	7.256	
	External	0	7.256	
	Δ	0	0	
0.015625M	Internal	0	7.259	
	External	0	7.259	
	Δ	0	0	
.0078125M	Internal	0	7.26	
	External	0	7.256	
	Δ	0	-0.004	
.00390625M	Internal	0	7.26	
	External	0.004	7.238	
	Δ	0.004	-0.022	
Trail 3				
Molarity		δTMS (ppm)	δCHCl3 (ppm)	
8M	Internal	0	den/overlapped	
	External	0.054	6.454	
	Δ	0.054	N/A	
4M	Internal	0	7.26	
	External	0.058	6.858	
	Δ	0.058	-0.402	
2M	Internal	0	7.26	
	External	0.037	7.057	
	Δ	0.037	-0.203	
1M	Internal	0	7.26	
	External	0.02	7.157	
	Δ	0.02	-0.103	
0.5M	Internal	0	7.26	
	External	0.011	7.208	
	Δ	0.011	-0.052	
0.25M	Internal	0	7.259	
	External	0.006	7.234	
	Δ	0.006	-0.025	
0.125M	Internal	0	7.257	
	External	0.003	7.247	
	Δ	0.003	-0.01	
0.0625M	Internal	0	7.26	
	External	0.002	7.254	
	Δ	0.002	-0.006	
0.03125M	Internal	0	7.256	
	External	0	7.256	
	Δ	0	0	
0.015625M	Internal	0	7.258	
	External	0.005	7.236	
	Δ	0.005	-0.022	
.0078125M	Internal	0	7.259	
	External	0	7.259	
	Δ	0	0	
.00390625M	Internal	0	7.259	
	External	0	7.255	
	Δ	0	-0.004	

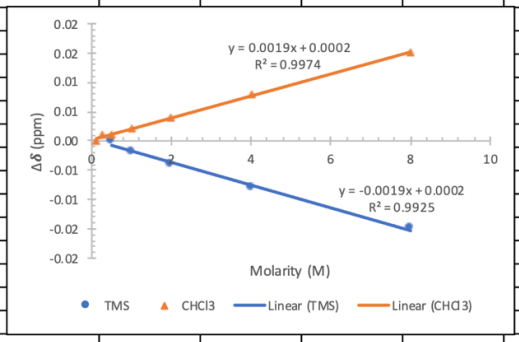
DBU

Molarity		δTMS (ppm)	δCHCl3 (ppm)		Molarity (M)	ΔδTMS (ppm	ΔδCHCl3 (ppm)		
4M	Internal	0	7.259		4	0.057	1.686		
	External	0.057	8.945		2	0.013	0.632		
	Δ	0.057	1.686		1	0.003	0.283		
					0.5	0	0.153		
					0.25	0	0.069		
2M	Internal	0	7.26		0.125	0	0.027		
	External	0.013	7.892		0.0625	0	0.016		
	Δ	0.013	0.632		0.03125	0	0.009		
					0.015625	0	0		
					0.0078125	0.008	0.008		
1M	Internal	0	7.26		0.00390625	0	0		
	External	0.003	7.543						
	Δ	0.003	0.283						
0.5M	Internal	0	7.264						
	External	0	7.417						
	Δ	0	0.153						
0.25M	Internal	0	7.26						
	External	0	7.329						
	Δ	0	0.069						
0.125M	Internal	0	7.267						
	External	0	7.294						
	Δ	0	0.027						
0.0625M	Internal	0	7.262						
	External	0	7.278						
	Δ	0	0.016						
		0	7.26						
.03125M	Internal	0	7.269						
	External	0	0.009						
	Δ								
.015625M	Internal	0	7.266						
	External	0	7.266						
	Δ	0	0						
.0078125M	Internal	0	7.264						
	External	0.008	7.272						
	Δ	0.008	0.008						
.00390625M	Internal	0	7.262						
	External	0	7.262						
	Δ	0	0						



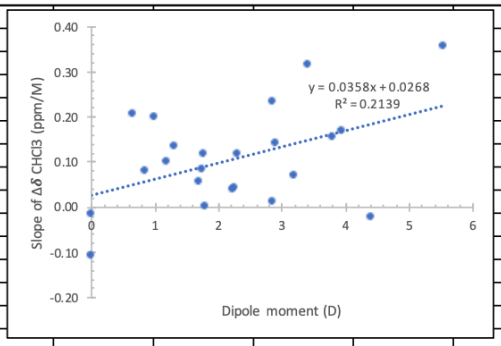
DCM

Molarity		δTMS (ppm)	δCHCl3 (ppm)		Molarity (M)	ΔδTMS (ppm	ΔδCHCl3 (ppm)			
8M	Internal	0	7.26		8	-0.015	0.015			
	External	-0.015	7.275		4	-0.008	0.008			
	Δ	-0.015	0.015		2	-0.004	0.004			
					1	-0.002	0.002			
					0.5	0	0.001			
4M	Internal	0	7.26		0.25	0	0.001			
	External	-0.008	7.268		0.125	0	0			
	Δ	-0.008	0.008							
2M	Internal	0	7.26							
	External	-0.004	7.264							
	Δ	-0.004	0.004							
1M	Internal	0	7.26							
	External	-0.002	7.262							
	Δ	-0.002	0.002							
0.5M	Internal	0	7.261							
	External	0	7.262							
	Δ	0	0.001							
0.25M	Internal	0	7.261							
	External	0	7.262							
	Δ	0	0.001							
0.125M	Internal	0	7.261							
	External	0	7.261							
	Δ	0	0							

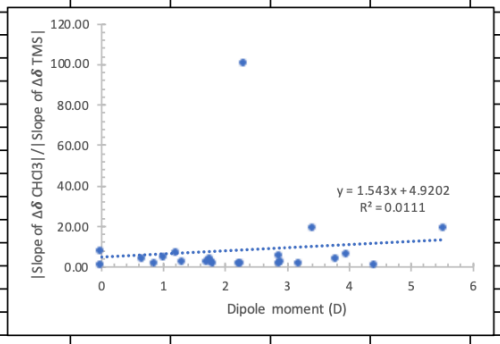


Dipole Plots

Solute	Dipole Moment (D)	Slope of Δδ CHCl3 (ppm/M)
HMPA	5.54	0.356
DBU	3.41	0.315
$(EtO)_3P=O$	2.86	0.232
TEA	0.66	0.205
$nBuNH_2$	1	0.2
DMSO	3.96	0.169
DMF	3.8	0.154
Acetone	2.9	0.142
Ether	1.3	0.134
Pyridine	2.3	0.118
EtOAc	1.78	0.116
Quinuclidine	1.2	0.099
THF	1.75	0.083
1-Pentyne	0.853	0.08
MeCN	3.2	0.069
MeOH	1.7	0.056
TFA	2.26	0.043
DMI	2.23	0.038
FNB	2.87	0.01
DCM	1.8	0.002
Benzene	0	-0.107
TPPO	4.4	-0.024
Hexafluorobenzene	0	-0.017

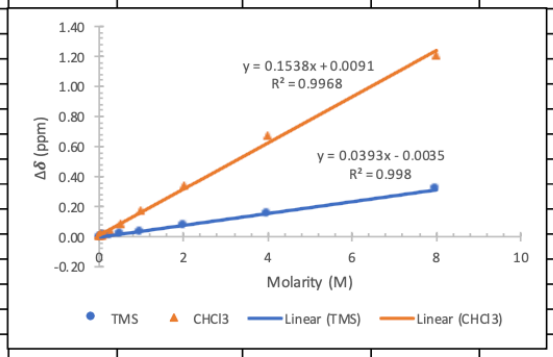


Solute	Dipole Moment (D)	|Slope of Δδ CHCl3| / |Slope of Δδ TMS|
Pyridine	2.3	100
DBU	3.41	18.83
HMPA	5.54	18.45
Benzene	0	7.11
Quinuclidine	1.2	6.52
DMSO	3.96	5.69
$(EtO)_3P=O$	2.86	5.16
$nBuNH_2$	1	4.32
DMF	3.8	3.91
TEA	0.66	3.52
THF	1.75	3.42
EtOAc	1.78	2.1
Acetone	2.9	1.98
MeOH	1.7	1.95
Ether	1.3	1.93
MeCN	3.2	1.63
1-Pentyne	0.853	1.3
DMI	2.23	1.29
TFA	2.26	1.02
DCM	1.8	1
FNB	2.87	0.96
Hexafluorobenzene	0	0.72
TPPO	4.4	0.24



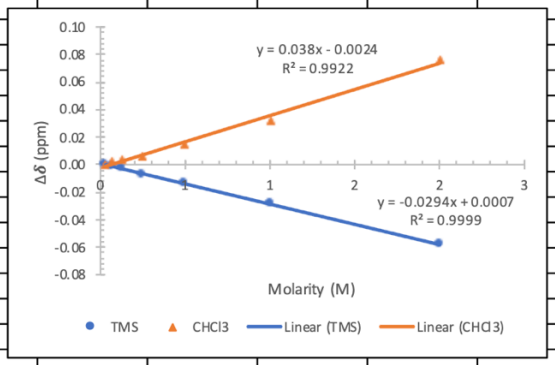
DMF

Molarity		δTMS (ppm)	δCHCl3 (ppm)		Molarity (M)	ΔδTMS (ppm)	ΔδCHCl3 (ppm)		
8M	Internal	0	7.26		8	0.317	1.209		
	External	0.317	8.469		4	0.146	0.676		
	Δ	0.317	1.209		2	0.068	0.335		
					1	0.034	0.171		
					0.5	0.017	0.087		
4M	Internal	0	7.26		0.25	0.009	0.025		
	External	0.146	7.936		0.125	0.005	0.023		
	Δ	0.146	0.676		0.0625	0.001	0.012		
					0.03125	0	0.005		
					0.015625	0.005	0.022		
2M	Internal	0	7.26		0.0078125	0	0.003		
	External	0.068	7.595		0.00390625	0	0.002		
	Δ	0.068	0.335						
1M	Internal	0	7.26						
	External	0.034	7.431						
	Δ	0.034	0.171						
0.5M	Internal	0	7.26						
	External	0.017	7.347						
	Δ	0.017	0.087						
0.25M	Internal	0	7.26						
	External	0.009	7.305						
	Δ	0.009	0.045						
0.125M	Internal	0	7.26						
	External	0.005	7.283						
	Δ	0.005	0.023						
0.0625M	Internal	0	7.269						
	External	0.001	7.281						
	Δ	0.001	0.012						
.03125M	Internal	0	7.26						
	External	0	7.265						
	Δ	0	0.005						
.015625M	Internal	0	7.263						
	External	0.005	7.285						
	Δ	0.005	0.022						
.0078125M	Internal	0	7.259						
	External	0	7.262						
	Δ	0	0.003						
.00390625M	Internal	0	7.259						
	External	0	7.261						
	Δ	0	0.002						



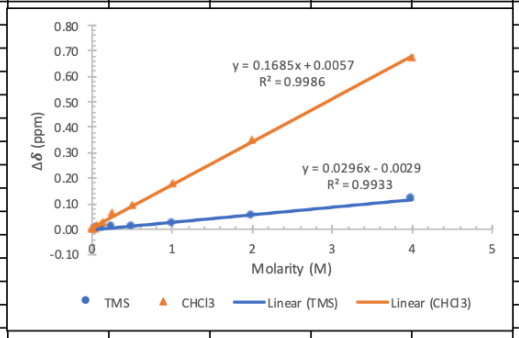
DMI

Molarity		δTMS (ppm)	δCHCl3 (ppm)		Molarity (M)	ΔδTMS (ppr	ΔδCHCl3 (ppm)		
2M	Internal	0	7.26		2	-0.058	0.076		
	External	-0.058	7.336		1	-0.029	0.032		
	Δ	-0.058	0.076		0.5	-0.014	0.014		
					0.25	-0.007	0.006		
					0.125	-0.003	0.004		
1M	Internal	0	7.26		0.0625	-0.001	0.002		
	External	-0.029	7.292		0.03125	0	0		
	Δ	-0.029	0.032						
0.5M	Internal	0	7.26						
	External	-0.014	7.274						
	Δ	-0.014	0.014						
0.25M	Internal	0	7.26						
	External	-0.007	7.266						
	Δ	-0.007	0.006						
0.125M	Internal	0	7.26						
	External	-0.003	7.264						
	Δ	-0.003	0.004						
0.0625M	Internal	0	7.261						
	External	-0.001	7.263						
	Δ	-0.001	0.002						
.03125M	Internal	0	7.261						
	External	0	7.261						
	Δ	0	0						
.015625M	Internal	0	7.259						
	External	-0.002	7.262						
	Δ	-0.002	0.003						



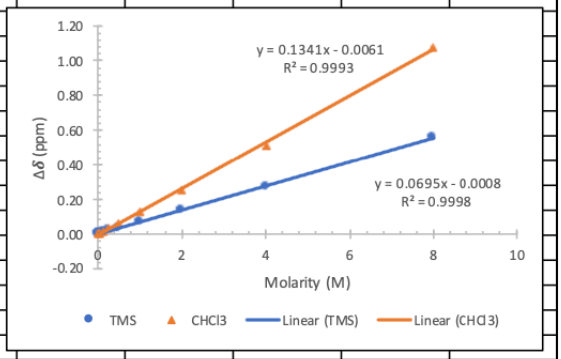
DMSO

Molarity		δTMS (ppm)	δCHCl3 (ppm)		Molarity (M)	ΔδTMS (ppm)	ΔδCHCl3 (ppm)			
4M	Internal	0	7.26		4	0.119	0.673			
	External	0.119	7.933		2	0.051	0.351			
	Δ	0.119	0.673		1	0.023	0.18			
					0.5	0.011	0.093			
					0.25	0.008	0.064			
2M	Internal	0	7.26		0.125	0.003	0.026			
	External	0.051	7.611		0.0625	0	0.014			
	Δ	0.051	0.351		0.03125	0	0			
					0.015625	0	0.004			
					0.0078125	0	0.005			
1M	Internal	0	7.26		0.00390625	0	0			
	External	0.023	7.44							
	Δ	0.023	0.18							
0.5M	Internal	0	7.26							
	External	0.011	7.353							
	Δ	0.011	0.093							
0.25M	Internal	0	7.26							
	External	0.008	7.324							
	Δ	0.008	0.064							
0.125M	Internal	0	7.26							
	External	0.003	7.286							
	Δ	0.003	0.026							
0.0625M	Internal	0	7.259							
	External	0	7.273							
	Δ	0	0.014							
.03125M	Internal	0	7.267							
	External	0	7.267							
	Δ	0	0							
.015625M	Internal	0	7.26							
	External	0	7.264							
	Δ	0	0.004							
.0078125M	Internal	0	7.262							
	External	0	7.267							
	Δ	0	0.005							
.00390625M	Internal	0	7.262							
	External	0	7.262							
	Δ	0	0							



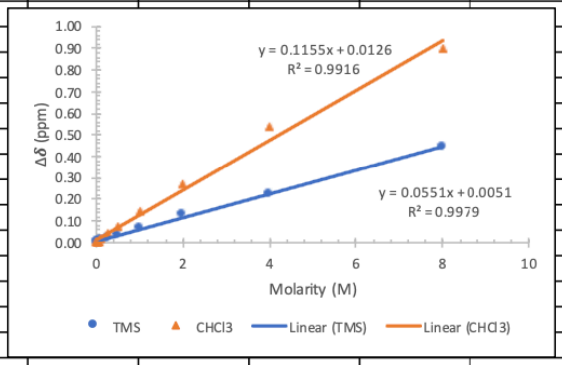
Ether

Molarity		δTMS (ppm)	δCHCl3 (ppm)		Molarity (M)	ΔδTMS (ppm)	ΔδCHCl3 (ppm)		
8M	Internal	0	7.26		8	0.558	1.079		
	External	0.558	8.339		4	0.272	0.514		
	Δ	0.558	1.079		2	0.136	0.248		
					1	0.07	0.124		
					0.5	0.035	0.061		
4M	Internal	0	7.26		0.25	0.018	0.031		
	External	0.272	7.774		0.125	0.009	0.016		
	Δ	0.272	0.514		0.0625	0.003	0.006		
					0.03125	0.002	0.004		
					0.015625	0	0		
2M	Internal	0	7.26		0.0078125	0.001	0.002		
	External	0.136	7.508		0.00390625	0	0		
	Δ	0.136	0.248						
1M	Internal	0	7.26						
	External	0.07	7.384						
	Δ	0.07	0.124						
0.5M	Internal	0	7.26						
	External	0.035	7.321						
	Δ	0.035	0.061						
0.25M	Internal	0	7.261						
	External	0.018	7.292						
	Δ	0.018	0.031						
0.125M	Internal	0	7.26						
	External	0.009	7.276						
	Δ	0.009	0.016						
0.0625M	Internal	0	7.261						
	External	0.003	7.267						
	Δ	0.003	0.006						
.03125M	Internal	0	7.26						
	External	0.002	7.264						
	Δ	0.002	0.004						
.015625M	Internal	0	7.261						
	External	0	7.261						
	Δ	0	0						
.0078125M	Internal	0	7.261						
	External	0.001	7.263						
	Δ	0.001	0.002						
.00390625M	Internal	0	7.261						
	External	0	7.261						
	Δ	0	0						



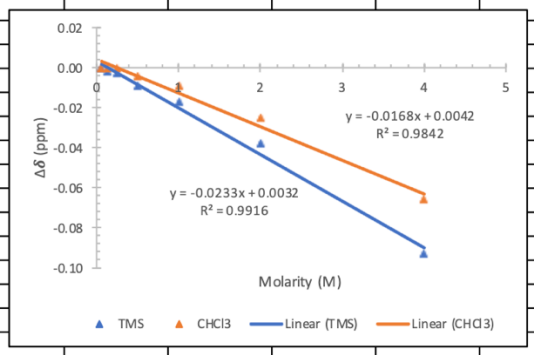
EtOAc

Molarity		δTMS (ppm)	δCHCl3 (ppm)		Molarity (M)	ΔδTMS (ppr	ΔδCHCl3 (ppm)		
8M	Internal	0	7.26		8	0.442	0.897		
	External	0.442	8.157		4	0.225	0.538		
	Δ	0.442	0.897		2	0.129	0.271		
					1	0.068	0.141		
					0.5	0.035	0.072		
4M	Internal	0	7.26		0.25	0.019	0.039		
	External	0.225	7.798		0.125	0.01	0.02		
	Δ	0.225	0.538		0.0625	0.002	0.004		
					0.03125	0.002	0.005		
					0.015625	0	0.002		
2M	Internal	0	7.262		0.0078125	0	0.005		
	External	0.129	7.533		0.00390625	0	0.005		
	Δ	0.129	0.271						
1M	Internal	0	7.26						
	External	0.068	7.401						
	Δ	0.068	0.141						
0.5M	Internal	0	7.26						
	External	0.035	7.332						
	Δ	0.035	0.072						
0.25M	Internal	0	7.26						
	External	0.019	7.299						
	Δ	0.019	0.039						
0.125M	Internal	0	7.26						
	External	0.01	7.28						
	Δ	0.01	0.02						
0.0625M	Internal	0	7.263						
	External	0.002	7.267						
	Δ	0.002	0.004						
.03125M	Internal	0	7.26						
	External	0.002	7.265						
	Δ	0.002	0.005						
.015625M	Internal	0	7.261						
	External	0	7.263						
	Δ	0	0.002						
.0078125M	Internal	0	7.26						
	External	0	7.265						
	Δ	0	0.005						
.00390625M	Internal	0	7.261						
	External	0	7.266						
	Δ	0	0.005						



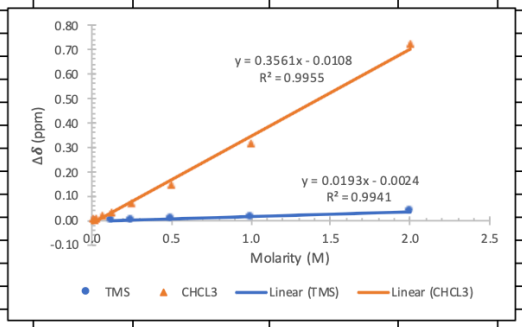
Hexafluorobenzene

Molarity		δTMS (ppm)	δCHCl3 (ppm)			Molarity (M)	ΔδTMS (ppr	ΔδCHCl3 (ppm)		
4M	Internal	0	7.26			4	-0.093	-0.066		
	External	-0.093	7.194			2	-0.038	-0.025		
	Δ	-0.093	-0.066			1	-0.017	-0.009		
						0.5	-0.009	-0.004		
						0.25	-0.003	0		
2M	Internal	0	7.26			0.125	-0.002	0		
	External	-0.038	7.235			0.0625	0	0		
	Δ	-0.038	-0.025			0.03125	-0.001	-0.002		
1M	Internal	0	7.259							
	External	-0.017	7.25							
	Δ	-0.017	-0.009							
0.5M	Internal	0	7.259							
	External	-0.009	7.255							
	Δ	-0.009	-0.004							
0.25M	Internal	0	7.26							
	External	-0.003	7.26							
	Δ	-0.003	0							
0.125M	Internal	0	7.259							
	External	-0.002	7.259							
	Δ	-0.002	0							
0.0625M	Internal	0	7.26							
	External	0	7.26							
	Δ	0	0							
.03125M	Internal	0	7.261							
	External	-0.001	7.259							
	Δ	-0.001	-0.002							



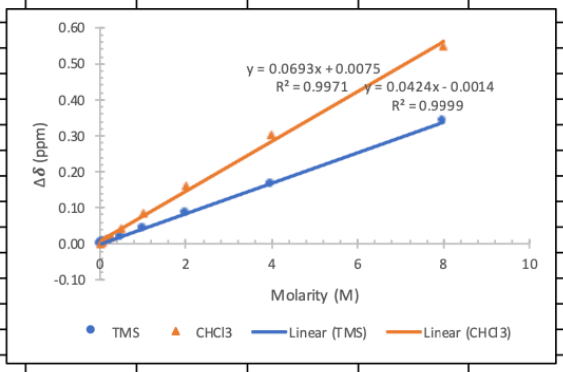
HMPA

Molarity		δTMS (ppm)	δCHCl3 (ppm)		Molarity (M)	ΔδTMS (ppm)	ΔδCHCl3 (ppm)		
4M	Internal	0	7.26		4	0.141	1.741		
	External	0.141	9.001		2	0.037	0.721		
	Δ	0.141	1.741		1	0.015	0.318		
					0.5	0.008	0.145		
					0.25	0.003	0.07		
2M	Internal	0	7.26		0.125	0	0.035		
	External	0.037	7.981		0.0625	0	0.018		
	Δ	0.037	0.721		0.03125	0	0.009		
					0.015625	0	0.002		
					0.0078125	0	0.006		
1M	Internal	0	7.26						
	External	0.015	7.578						
	Δ	0.015	0.318						
0.5M	Internal	0	7.26						
	External	0.008	7.405						
	Δ	0.008	0.145						
0.25M	Internal	0	7.26						
	External	0.003	7.33						
	Δ	0.003	0.07						
0.125M	Internal	0	7.26						
	External	0	7.295						
	Δ	0	0.035						
0.0625M	Internal	0	7.26						
	External	0	7.278						
	Δ	0	0.018						
.03125M	Internal	0	7.26						
	External	0	7.269						
	Δ	0	0.009						
.015625M	Internal	0	7.263						
	External	0	7.265						
	Δ	0	0.002						
.0078125M	Internal	0	7.263						
	External	0	7.269						
	Δ	0	0.006						



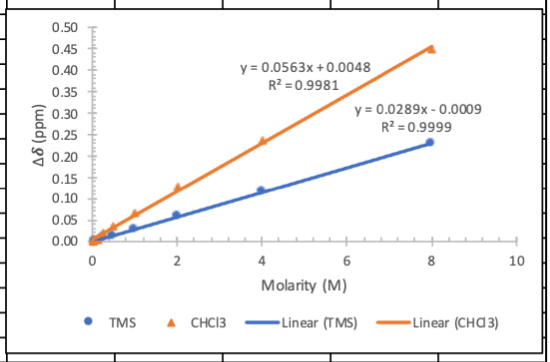
MeCN

Molarity		δTMS (ppm)	δCHCl3 (ppm)		Molarity (M)	ΔδTMS (ppr	ΔδCHCl3 (ppm)		
8M	Internal	0.000	7.260		8	0.339	0.55		
	External	0.339	7.810		4	0.167	0.301		
	Δ	0.339	0.550		2	0.082	0.159		
					1	0.04	0.084		
					0.5	0.02	0.042		
4M	Internal	0.000	7.260		0.25	0.009	0.02		
	External	0.167	7.561		0.125	0.005	0.012		
	Δ	0.167	0.301		0.0625	0.003	0.006		
					0.03125	0	0		
					0.015625	0	0.002		
2M	Internal	0.000	7.260		0.0078125	0	0		
	External	0.082	7.419		0.00390625	0	0		
	Δ	0.082	0.159						
1M	Internal	0.000	7.259						
	External	0.040	7.343						
	Δ	0.040	0.084						
0.5M	Internal	0.000	7.260						
	External	0.020	7.302						
	Δ	0.020	0.042						
0.25M	Internal	0.000	7.261						
	External	0.009	7.281						
	Δ	0.009	0.020						
0.125M	Internal	0.000	7.260						
	External	0.005	7.272						
	Δ	0.005	0.012						
0.0625M	Internal	0.000	7.260						
	External	0.003	7.266						
	Δ	0.003	0.006						
.03125M	Internal	0.000	7.262						
	External	0.000	7.262						
	Δ	0.000	0.000						
.015625M	Internal	0.000	7.260						
	External	0.000	7.262						
	Δ	0.000	0.002						
.0078125M	Internal	0.000	7.261						
	External	0.000	7.261						
	Δ	0.000	0.000						
.00390625M	Internal	0.000	7.261						
	External	0.000	7.261						
	Δ	0.000	0.000						



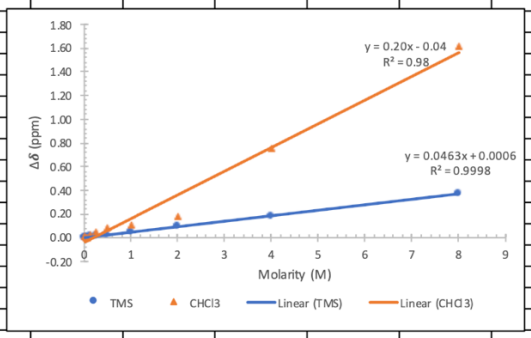
MeOH

Molarity		δTMS (ppm)	δCHCl3 (ppm)		Molarity (M)	ΔδTMS (ppr	ΔδCHCl3 (ppm)		
8M	Internal	0	7.26		8	0.229	0.448		
	External	0.229	7.708		4	0.116	0.237		
	Δ	0.229	0.448		2	0.058	0.127		
					1	0.028	0.068		
					0.5	0.013	0.036		
4M	Internal	0	7.26		0.25	0.007	0.019		
	External	0.116	7.497		0.125	0.002	0.006		
	Δ	0.116	0.237		0.0625	0	0.004		
					0.03125	0	0.002		
					0.015625	0	0		
2M	Internal	0	7.26		0.0078125	0	0		
	External	0.058	7.387						
	Δ	0.058	0.127						
1M	Internal	0	7.26						
	External	0.028	7.328						
	Δ	0.028	0.068						
0.5M	Internal	0	7.26						
	External	0.013	7.296						
	Δ	0.013	0.036						
0.25M	Internal	0	7.26						
	External	0.007	7.279						
	Δ	0.007	0.019						
0.125M	Internal	0	7.262						
	External	0.002	7.268						
	Δ	0.002	0.006						
0.0625M	Internal	0	7.26						
	External	0	7.264						
	Δ	0	0.004						
.03125M	Internal	0	7.26						
	External	0	7.262						
	Δ	0	0.002						
.015625M		0	7.261						
	Internal	0	7.261						
	External	0	0						
	Δ								
.0078125M		0	7.261						
	Internal	0	7.261						
	External	0	0						
	Δ								



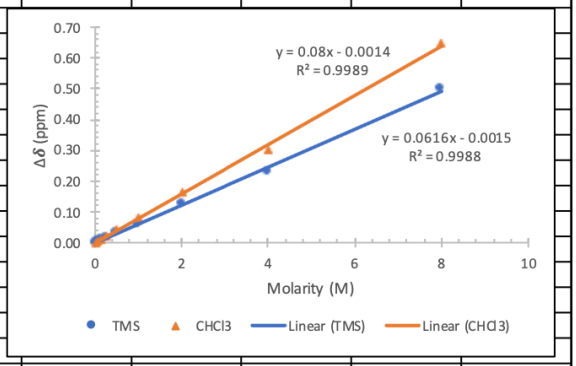
nBuNH2

Molarity		δTMS (ppm)	δCHCl3 (ppm)		Molarity (M)	ΔδTMS (ppr	ΔδCHCl3 (ppm)				
8M	Internal	0.000	7.260		8	0.371	1.616				
	External	0.371	8.876		4	0.184	0.752				
	Δ	0.371	1.616		2	0.095	0.179				
					1	0.049	0.104				
					0.5	0.025	0.085				
4M	Internal	0	7.260		0.25	0.013	0.042				
	External	0.184	8.012		0.125	0.006	0.023				
	Δ	0.184	0.752		0.0625	0.001	0.004				
					0.03125	0.000	0				
					0.015625	0.002	0.008				
2M	Internal	0.000	7.260								
	External	0.095	7.439								
	Δ	0.095	0.179								
1M	Internal	0.000	7.259								
	External	0.049	7.363								
	Δ	0.049	0.104								
0.5M	Internal	0.000	7.260								
	External	0.025	7.345								
	Δ	0.025	0.085								
0.25M	Internal	0.000	7.260								
	External	0.013	7.302								
	Δ	0.013	0.042								
0.125M	Internal	0.000	7.259								
	External	0.006	7.282								
	Δ	0.006	0.023								
0.0625M	Internal	0.000	7.268								
	External	0.001	7.272								
	Δ	0.001	0.004								
.03125M	Internal	0.000	7.264								
	External	0.000	7.264								
	Δ	0.000	0.000								
.015625M	Internal	0.000	7.262								
	External	0.002	7.270								
	Δ	0.002	0.008								



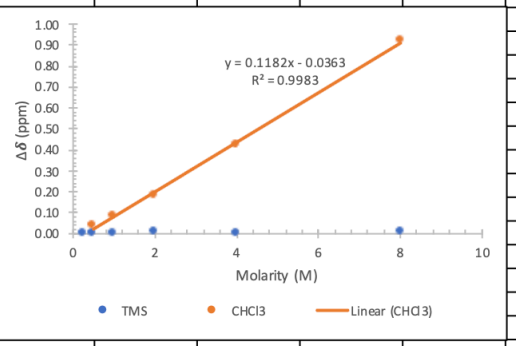
Pentyne

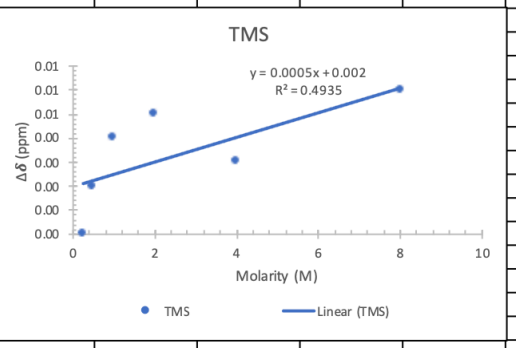
Molarity		δTMS (ppm)	δCHCl3 (ppm)		Molarity (M)	ΔδTMS (ppm)	ΔδCHCl3 (ppm)		
8M	Internal	0	7.26		8	0.498	0.646		
	External	0.498	7.906		4	0.231	0.301		
	Δ	0.498	0.646		2	0.123	0.161		
					1	0.061	0.08		
					0.5	0.031	0.04		
4M	Internal	0	7.26		0.25	0.015	0.02		
	External	0.231	7.561		0.125	0.008	0.011		
	Δ	0.231	0.301		0.0625	0.004	0.005		
					0.03125	0	0		
2M	Internal	0	7.26						
	External	0.123	7.421						
	Δ	0.123	0.161						
1M	Internal	0	7.26						
	External	0.061	7.34						
	Δ	0.061	0.08						
0.5M	Internal	0	7.26						
	External	0.031	7.3						
	Δ	0.031	0.04						
0.25M	Internal	0	7.26						
	External	0.015	7.28						
	Δ	0.015	0.02						
0.125M	Internal	0	7.26						
	External	0.008	7.271						
	Δ	0.008	0.011						
0.0625M	Internal	0	7.26						
	External	0.004	7.265						
	Δ	0.004	0.005						
.03125M	Internal	0	7.261						
	External	0	7.261						
	Δ	0	0						



Pyridine

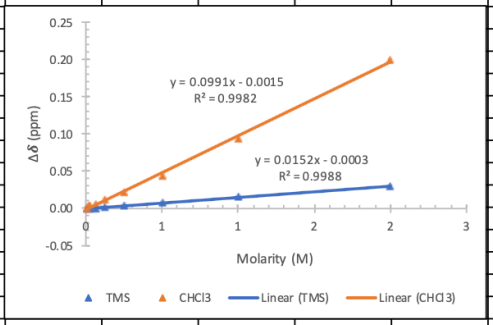
Molarity		δTMS (ppm)	δCHCl3 (ppm)		Molarity (M)	ΔδTMS (ppm)	ΔδCHCl3 (ppm)			
8M	Internal	0	7.265		8	0.006	0.919			
	External	0.006	8.184		4	0.003	0.421			
	Δ	0.006	0.919		2	0.005	0.185			
					1	0.004	0.085			
					0.5	0.002	0.04			
4M	Internal	0	7.259		0.25	0.000	N/A			
	External	0.003	7.68		0.125	0.000	N/A			
	Δ	0.003	0.421		0.0625	0.000	N/A			
					0.03125	0.000	N/A			
2M	Internal	0	7.26							
	External	0.005	7.445							
	Δ	0.005	0.185							
1M	Internal	0	7.26							
	External	0.004	7.345							
	Δ	0.004	0.085							
0.5M	Internal	0	7.26							
	External	0.002	7.3							
	Δ	0.002	0.04							
0.25M	Internal	0	7.259							
	External	0	Iden/overlapped							
	Δ	0	N/A							
0.125M	Internal	0	7.259							
	External	0	Iden/overlapped							
	Δ	0	N/A							
0.0625M	Internal	0	7.265							
	External	0	Iden/overlapped							
	Δ		N/A							
0.03125M	Internal	0	7.26							
	External	0	Iden/overlapped							
	Δ	0	N/A							





Quinuclidine

Molarity		δTMS (ppm)	δCHCl3 (ppm)			Molarity (M)	ΔδTMS (ppr	ΔδCHCl3 (ppm)			
2M	Internal	0	7.259			2	0.03	0.2			
	External	0.03	7.459			1	0.015	0.093			
	Δ	0.03	0.2			0.5	0.007	0.044			
						0.25	0.004	0.022			
						0.125	0.002	0.011			
1M	Internal	0	7.26			0.0625	0	0.006			
	External	0.015	7.353			0.03125	0	0.003			
	Δ	0.015	0.093			0.015625	0	0.003			
						0.0078125	0	0			
						0.00390625	0	0			
0.5M	Internal	0	7.26								
	External	0.007	7.304								
	Δ	0.007	0.044								
0.25M	Internal	0	7.26								
	External	0.004	7.282								
	Δ	0.004	0.022								
0.125M	Internal	0	7.26								
	External	0.002	7.271								
	Δ	0.002	0.011								
0.0625M	Internal	0	7.259								
	External	0	7.265								
	Δ	0	0.006								
.03125M	Internal	0	7.26								
	External	0	7.263								
	Δ	0	0.003								
.015625M	Internal	0	7.26								
	External	0	7.263								
	Δ	0	0.003								
.0078125M	Internal	0	7.26								
	External	0	7.26								
	Δ	0	0								
.00390625M	Internal	0	7.26								
	External	0	7.26								
	Δ	0	0								

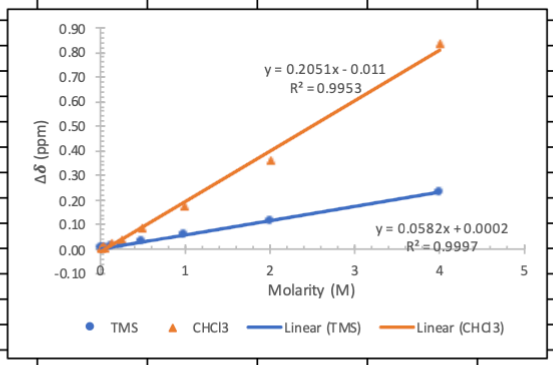


Solvent Comparison

		δTMS (ppm)	δCHCl3 (ppm)	
2M Ether (CDCl3)	Internal	0	7.26	
	External	0.136	7.508	
	Δ	0.136	0.248	
		δTMS (ppm)	δBenzene (ppm)	
2M Ether (Benzene-d6)	Internal	0	7.157	
	External	0.138	7.316	
	Δ	0.138	0.159	
		δTMS (ppm)	δAcetone (ppm)	
2M Ether (Acetone-d6)	Internal	0	2.044	
	External	0.048	2.1	
	Δ	0.048	0.056	
		δTMS (ppm)	δDMSO (ppm)	
2M Ether (DMSO-d6)	Internal	0	0	
	External	0	0	
	Δ	0	0	
		δTMS (ppm)	δMeOH (ppm)	
2M Ether (MeOD-d4)	Internal	0	3.319	
	External	0.014	3.297	
	Δ	0.014	-0.022	

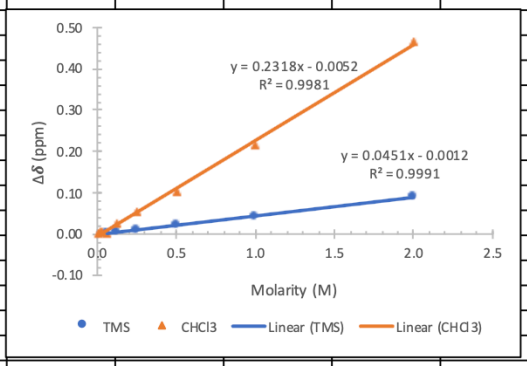
TEA

Molarity		δTMS (ppm)	δCHCl3 (ppm)		Molarity (M)	ΔδTMS (ppr	ΔδCHCl3 (ppm)		
4M	Internal	0	7.26		4	0.233	0.834		
	External	0.233	8.094		2	0.115	0.361		
	Δ	0.233	0.834		1	0.06	0.173		
					0.5	0.031	0.086		
					0.25	0.014	0.037		
2M	Internal	0	7.26		0.125	0.009	0.024		
	External	0.115	7.621		0.0625	0.002	0.004		
	Δ	0.115	0.361		0.03125	0.002	0.007		
					0.015625	0	0.003		
					0.0078125	0	0		
1M	Internal	0	7.26		0.00390625	0	0		
	External	0.06	7.433						
	Δ	0.06	0.173						
0.5M	Internal	0	7.26						
	External	0.031	7.346						
	Δ	0.031	0.086						
0.25M	Internal	0	7.265						
	External	0.014	7.302						
	Δ	0.014	0.037						
0.125M	Internal	0	7.26						
	External	0.009	7.284						
	Δ	0.009	0.024						
0.0625M	Internal	0	7.265						
	External	0.002	7.269						
	Δ	0.002	0.004						
.03125M	Internal	0	7.259						
	External	0.002	7.266						
	Δ	0.002	0.007						
.015625M	Internal	0	7.26						
	External	0	7.263						
	Δ	0	0.003						
.0078125M	Internal	0	7.262						
	External	0	7.262						
	Δ	0	0						
.00390625M	Internal	0	7.261						
	External	0	7.261						
	Δ	0	0						



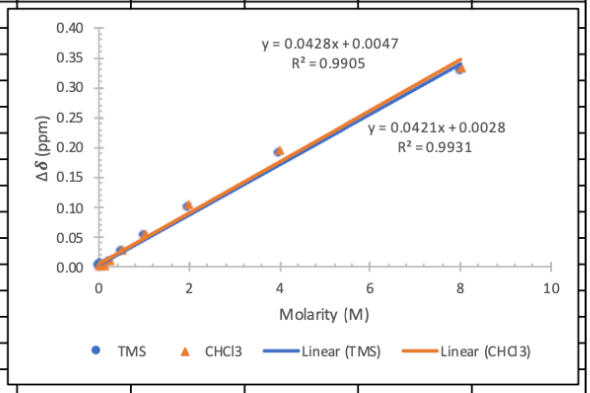
TEP

Molarity		δTMS (ppm)	δCHCl3 (ppm)		Molarity (M)	ΔδTMS (ppr	ΔδCHCl3 (ppm)		
4M	Internal	0	7.26		4	0.2	1.057		
	External	0.2	8.317		2	0.089	0.466		
	Δ	0.2	1.057		1	0.043	0.215		
					0.5	0.022	0.104		
					0.25	0.011	0.052		
2M	Internal	0	7.26		0.125	0.005	0.026		
	External	0.089	7.726		0.0625	0	0.003		
	Δ	0.089	0.466		0.03125	0	0.007		
					0.015625	0	0.004		
					0.0078125	0	0.002		
1M	Internal	0	7.26						
	External	0.043	7.475						
	Δ	0.043	0.215						
0.5M	Internal	0	7.26						
	External	0.022	7.364						
	Δ	0.022	0.104						
0.25M	Internal	0	7.26						
	External	0.011	7.312						
	Δ	0.011	0.052						
0.125M	Internal	0	7.26						
	External	0.005	7.286						
	Δ	0.005	0.026						
0.0625M	Internal	0	7.268						
	External	0	7.271						
	Δ	0	0.003						
0.03125M	Internal	0	7.26						
	External	0	7.267						
	Δ	0	0.007						
0.015625M	Internal	0	7.26						
	External	0	7.264						
	Δ	0	0.004						
0.0078M	Internal	0	7.26						
	External	0	7.262						
	Δ	0	0.002						



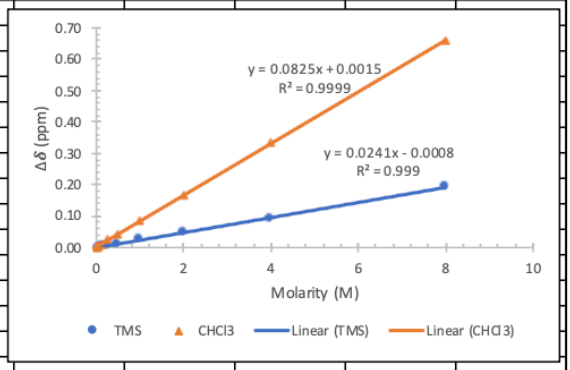
TFA

Molarity		δTMS (ppm)	δCHCl3 (ppm)		Molarity (M)	ΔδTMS (ppr	ΔδCHCl3 (ppm)		
8M	Internal	0	7.26		8	0.328	0.333		
	External	0.328	7.593		4	0.188	0.196		
	Δ	0.328	0.333		2	0.099	0.105		
					1	0.051	0.054		
					0.5	0.025	0.027		
4M	Internal	0	7.26		0.25	0.007	0.009		
	External	0.188	7.456		0.125	0	0		
	Δ	0.188	0.196		0.0625	0.003	0.004		
					0.03125	0	0.003		
					0.015625	0	0		
2M	Internal	0	7.26						
	External	0.099	7.365						
	Δ	0.099	0.105						
1M	Internal	0	7.26						
	External	0.051	7.314						
	Δ	0.051	0.054						
0.5M	Internal	0	7.26						
	External	0.025	7.287						
	Δ	0.025	0.027						
0.25M	Internal	0	7.26						
	External	0.007	7.269						
	Δ	0.007	0.009						
0.125M	Internal	0	7.262						
	External	0	7.262						
	Δ	0	0						
0.0625M	Internal	0	7.26						
	External	0.003	7.264						
	Δ	0.003	0.004						
.03125M	Internal	0	7.259						
	External	0	7.262						
	Δ	0	0.003						
.015625M	Internal	0	7.261						
	External	0	7.261						
	Δ	0	0						



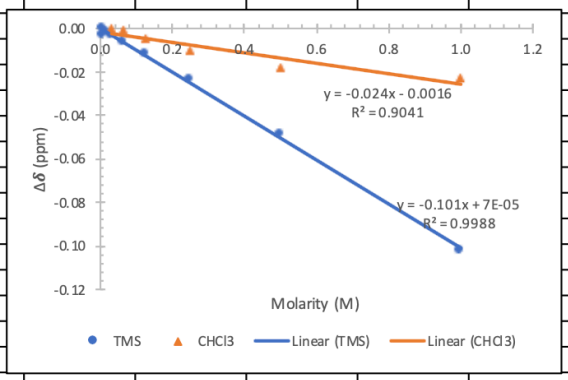
THF

Molarity		δTMS (ppm)	δCHCl3 (ppm)		Molarity (M)	ΔδTMS (ppr	ΔδCHCl3 (ppm)		
8M	Internal	0	7.26		8	0.194	0.659		
	External	0.194	7.919		4	0.091	0.336		
	Δ	0.194	0.659		2	0.046	0.166		
					1	0.024	0.085		
					0.5	0.012	0.043		
4M	Internal	0	7.26		0.25	0.006	0.025		
	External	0.091	7.596		0.125	0.004	0.012		
	Δ	0.091	0.336		0.0625	0	0.005		
					0.03125	0	0.003		
					0.015625	0	0.002		
2M	Internal	0	7.26		0.0078125	0	0		
	External	0.046	7.426		0.00390625	0	0		
	Δ	0.046	0.166						
1M	Internal	0	7.26						
	External	0.024	7.345						
	Δ	0.024	0.085						
0.5M	Internal	0	7.26						
	External	0.012	7.303						
	Δ	0.012	0.043						
0.25M	Internal	0	7.26						
	External	0.006	7.285						
	Δ	0.006	0.025						
0.125M	Internal	0	7.261						
	External	0.004	7.273						
	Δ	0.004	0.012						
0.0625M	Internal	0	7.261						
	External	0	7.266						
	Δ	0	0.005						
.03125M	Internal								
	External	0	7.26						
	Δ	0	7.263						
		0	0.003						
.015625M	Internal	0	7.26						
	External	0	7.262						
	Δ	0	0.002						
.0078125M	Internal	0	7.26						
	External	0	7.26						
	Δ	0	0						
.00390625M	Internal	0	7.261						
	External	0	7.261						
	Δ	0	0						



TPPO

Molarity		δTMS (ppm)	δCHCl3 (ppm)		Molarity (M)	ΔδTMS (ppm	ΔδCHCl3 (ppm)		
1M	Internal	0	7.26		1	-0.102	-0.023		
	External	-0.102	7.237		0.5	-0.049	-0.018		
	Δ	-0.102	-0.023		0.25	-0.024	-0.01		
					0.125	-0.012	-0.005		
					0.0625	-0.006	-0.001		
0.5M	Internal	0	7.26		0.03125	-0.003	0		
	External	-0.049	7.242		0.015625	-0.002	0		
	Δ	-0.049	-0.018		0.0078125	-0.003	0		
					0.00390625	0	0		
0.25M	Internal	0	7.26						
	External	-0.024	7.25						
	Δ	-0.024	-0.01						
0.125M	Internal	0	7.26						
	External	-0.012	7.255						
	Δ	-0.012	-0.005						
0.0625M	Internal	0	7.259						
	External	-0.006	7.258						
	Δ	-0.006	-0.001						
	Internal	0	7.259						
0.03125M	External	-0.003	7.259						
	Δ	-0.003	0						
0.015625M	Internal	0	7.26						
	External	-0.002	7.26						
	Δ	-0.002	0						
.0078125M	Internal	0	7.258						
	External	-0.003	7.258						
	Δ	-0.003	0						
.00390625M	Internal	0	7.261						
	External	0	7.261						
	Δ	0	0						



Supplementary Information for Chapter II

I. General Experimental Protocols for Chapters 2, 3, and 4

"**^{13}C and ^{1}H NMR spectra** were recorded on a Bruker Avance III (HD-500)"[1] or a Bruker AX-400 spectrometer. "Chemical shifts for spectra in $CDCl_3$ are referenced to TMS at δ 0.00 ppm. A non-first order multiplet, or a doublet in a ^{1}H NMR spectrum are denoted as 'nfom' or 'nfod' respectively. Multiplets are described by: chemical shift (ppm) [multiplicity, coupling constant(s) in Hz, integral value to the nearest integer, and assignment of the environment within the structure by indicating neighboring atoms or by numbering of the carbon atom to which the proton is attached]. Analysis of coupling constants was done using methods published previously.[2,3] ^{13}C NMR chemical shifts are those measured in the 1D spectrum. Carbon chemical shifts in $CDCl_3$ are referenced to δ 77.16 ppm. Structural assignments were guided by information from gCOSY, gHSQC, gHMBC, and gNOESY experiments.

Infrared spectra were taken on a Bruker Alpha II Spectrometer in the attenuated total reflectance (ATR) mode. Absorption maxima are given in cm^{-1}. The samples were prepared as thin films made by evaporation of a DCM solution on a diamond window.

High-resolution **mass spectrometry** (HRMS) was performed in ESI-TOF mode on a Thermo Orbitrap Velos instrument having a mass accuracy of ≤3 ppm. Pierce™ LTQ was used as an external calibrant. The samples were injected directly into the ion source.

Medium pressure liquid **chromatography** (MPLC) was used to purify most new compounds. Hand-packed silica gel columns (Teledyne RediSep Rf Gold®; normal-phase, 20–40 μm, 60 Å pore size,) were used. The apparatus was constructed with a HPLC pump (Waters model 510), differential refractive index detector (Waters R401), and UV detector (Gilson 111 UV). Preparative flash chromatography was done on Agela silica gel (230–400 mesh). Thin layer chromatography (TLC) was carried out using silica-gel coated, aluminum-backed plates that were visualized first by UV light and, then, by staining with a solution of $KMnO_4$ and heating.

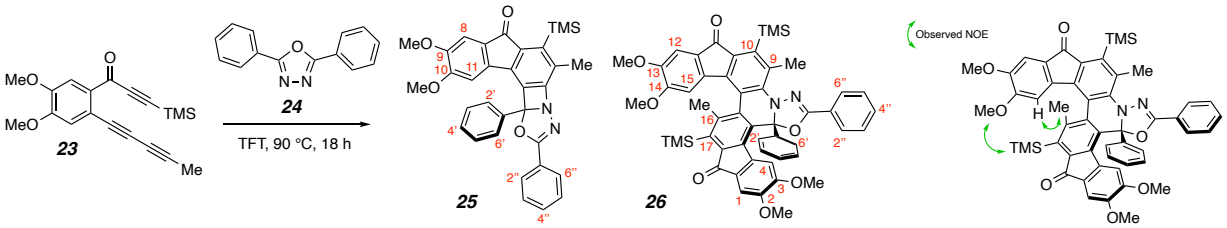
Reaction temperatures refer to the temperatures of an external heating oil bath or block heater. HDDA reactions, including reactions at temperatures higher than that of the boiling point of the solvent, were done in a screw-top culture tube that was capped with an inert Teflon®-lined closure.

Melting points were recorded on a Mel-Temp® (Laboratory Devices) apparatus as a range with the first number representing the initial point of liquification (or degradation) of the crystal and the final point being that at which full liquification or degradation was observed. A Bristoline Bristolscope microscope with a polarizing filter was used to assess crystallinity of solid samples."[1]

Triyne substrate **23**[4] was synthesized following literature reported methods.

II. Experimental Procedures and Characterization Data for New Compounds

(±)-9,10-Dimethoxy-5-methyl-2,11d-diphenyl-6-(trimethylsilyl)fluoreno[4',3':3,4]azeto[2,1-*b*][1,3,4]oxadiazol-7(11d*H*)-one (25)
and
(±)-2,3,13,14-Tetramethoxy-9,16-dimethyl-4d,6-diphenyl-10,17-bis(trimethylsilyl)-11*H*-diindeno[1,2-*a*:1',2'-*i*][1,3,4]oxadiazolo[3,2-*f*]phenanthridine-11,18(4d*H*)-dione (26)



In a threaded culture tube, 2,5-diphenyl-1,3,4-oxadiazole[5] (**24**, 51 mg, 0.23 mmol, 0.75 equiv) was added to a solution of triyne **23** (100 mg, 0.31 mmol, 1 equiv) in α,α,α-trifluorotoluene (10 mL). The tube was closed with a Teflon®-lined screw cap, and the solution was heated at 90 °C for 18 h. The solvent was removed and the residue was purified by MPLC (3:1 hex:EtOAc) to afford **26** (71 mg, 0.082 mmol, 53%) and **25** (4 mg, 0.082 mmol, 3%), each as an orange crystalline solid.

Data for 25 (the 1:1 adduct)

^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.03–7.99 (nfod, J_{app} = 8.6 Hz, 2H, *H2"* and *H6"*), 7.75–7.69 (nfom, 2H, *H2'* and *H6'*), 7.53–7.40 (m, 6H, *H3'*, *H3"*, *H4'*, *H4"*, *H5'*, and *H5"*), 7.15 (s, 1H, *H*8), 6.52 (s, 1H, *H*11), 3.90 (s, 3H, C9OC*H*$_3$), 3.72 (s, 3H, C10OC*H*$_3$), 2.46 (s, 3H, Ar-C*H*$_3$), and 1.55 [s, 9H, Si(C*H*$_3$)$_3$].

^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ 193.3 (C7), 163.83 (C2 or C4a), 163.79 (C2 or C4a), 154.3 (C10), 150.3 (C9), 147.0, 138.9, 138.1, 135.7, 135.6, 131.9 (C2" and C6"), 131.5, 131.1, 130.4 (C2' and C6'), 129.0, 128.7, 127.86 (C4"), 127.85, 126.5 (C4'), 125.8, 110.2 (C11d), 107.1 (C8), 105.6 (C11), 56.4 (C9-OCH$_3$ or C8-OCH$_3$), 56.3 (C9-OCH$_3$ or C8-OCH$_3$), 17.1 (C5-CH$_3$), and 2.7 [C6-Si(CH$_3$)$_3$].

from HSQC, from HMBC, from NOESY

IR (neat): 3395, 3067, 3004, 2939, 2900, 2836, 1707, 1594, 1495, 1093, and 1058 cm^{-1}.

HRMS (ESI-TOF) *m/z* (rel int): [M+H$^+$] calcd for $C_{33}H_{31}N_2O_4Si^+$, 547.2048; found, 547.2033 (2%); [M+H$^+$–PhCN] calcd for $C_{26}H_{26}NO_4Si^+$, 444.1626; found, 444.1613 (100%).

mp: 124–127 °C.

Data for 26 (the 2:1 adduct)

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.66–7.63 (nfod, J_{app} = 8.1 Hz, 2H, *H2''/6''*), 7.63–7.59 (nfod, J_{app} = 8.1 Hz, 2H, *H2'/6'*), 7.40–7.29 (m, 6H, *H3'*/5', *H3''/5''*, *H4'*, and *H4''*), 7.18 (s, 1H, *H1*), 7.12 (s, 1H, *H12*), 6.99 (s, 1H, *H4*), 6.79 (s, 1H, *H15*), 3.94 (s, 3H, C2OCH_3), 3.90 (s, 3H, C13OCH_3), 3.73 (s, 3H, C14OCH_3), 3.47 (s, 3H, C3OCH_3), 2.56 (s, 3H, C9CH_3), 2.47 (s, 3H, C16CH_3), 0.45 [s, 9H, C10Si(CH_3)$_3$], and 0.44 [s, 9H, C17Si(CH_3)$_3$].

^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ 194.2 (C18), 193.5 (C11), 153.9 (C14), 153.6 (C3), 151.3 (C6), 149.9 (C13), 149.4 (C2), 143.9, 142.69, 142.65, 141.7, 141.6, 139.8, 139.30, 139.25, 139.0, 138.7, 137.7, 136.9, 134.74, 134.71, 130.7 (C4''), 130.2, 129.0, 128.9, 127.62, 127.60, 127.2, 126.3, 125.3, 123.0, 109.4 (C4), 106.7 (C1), 106.1 (C12), 104.5 (C15), 99.9 (C4d), 56.5 (C14-OCH_3), 56.26 (C4- or C13-OCH_3), 56.24 (C4- or C13-OCH_3), 56.0 (C3-OCH_3), 24.6 (C16-CH_3), 20.2 (C9-CH_3), 3.5 [C17-Si(CH_3)$_3$], and 2.3 [C10-Si(CH_3)$_3$].

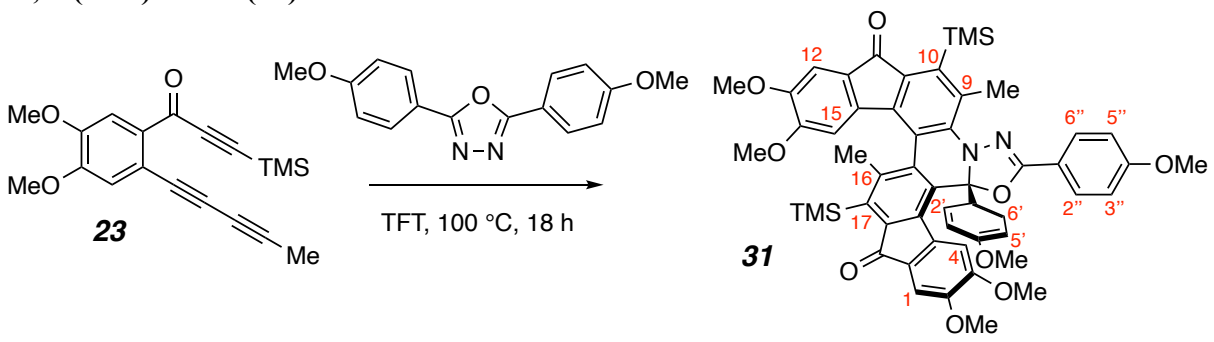
from HSQC, from HMBC, from NOESY

IR (neat): 3062, 2999, 2932, 2836, 1703, 1493, and 1022 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{52}H_{51}N_2O_7Si_2^+$, 871.3229; found, 871.3210.

mp: 343–352 °C (with decomposition).

(±)-2,3,13,14-Tetramethoxy-4d,6-bis(4-methoxyphenyl)-9,16-dimethyl-10,17-bis(trimethylsilyl)-11*H*-diindeno[1,2-*a*:1',2'-*i*][1,3,4]oxadiazolo[3,2-*f*]phenanthridine-11,18(4d*H*)-dione (31)



In a threaded culture tube, 2,5-bis(4-methoxyphenyl)-1,3,4-oxadiazole[5] (33 mg, 0.12 mmol, 0.75 equiv) was added to a solution of triyne **23** (50 mg, 0.15 mmol, 1 equiv) in α,α,α-trifluorotoluene (5 mL). The tube was closed with a Teflon®-lined cap, and the solution was heated at 100 °C for 18 h. The solvent was removed and the residue was purified by MPLC (1.5:1 hex:EtOAc) to afford **31** (33 mg, 0.035 mmol, 46%) as a red-orange crystalline solid.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.56 (nfod, J_{app} = 8.9 Hz, 2H, *H2"/6"*), 7.51 (nfod, J_{app} = 8.8 Hz, 2H, *H2'/6'*), 7.18 (s, 1H, *H1*), 7.11 (s, 1H, *H12*), 7.08 (s, 1H, *H4*), 6.84–6.79 (m, 4H, *H3'/5'* and *H3"*/5"), 6.76 (s, 1H, *H15*), 3.94 (s, 3H, C2OCH_3), 3.90 (s, 3H, C13OCH_3), 3.79 (s, 3H, C4"OCH_3), 3.718 (s, 3H, C4'OCH_3 or C14OCH_3), 3.716 (s, 3H, C4'OCH_3 or C14OCH_3), 3.52 (s, 3H, C3OCH_3), 2.56 (s, 3H, C9CH_3), 2.45 (s, 3H, C16CH_3), 0.44 [s, 9H, C10Si(CH_3)$_3$], and 0.43 [s, 9H, C17Si(CH_3)$_3$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 194.4 (C17), 193.5 (C11), 161.6 (C4"), 161.0 (C4'), 153.9 (C14), 153.6 (C3), 151.4 (C6), 149.8 (C13), 149.4 (C2), 143.8, 142.7, 142.5, 141.7, 141.6, 139.8, 139.6, 139.4, 139.1, 137.9, 136.7, 135.1, 134.8, 130.4, 129.2 (C2'/6'), 128.0 (C2"/6"), 127.7, 127.3, 123.0, 117.8, 114.4, 114.3, 109.6, 106.6, 106.1, 104.4, 99.7 (C4d), 56.5, 56.28, 56.26, 56.1, 55.6, 55.4, 24.6 (C16CH_3), 20.2 (C9CH_3), 3.5 [C17-Si(CH_3)$_3$], and 2.3 [C10-Si(CH_3)$_3$].

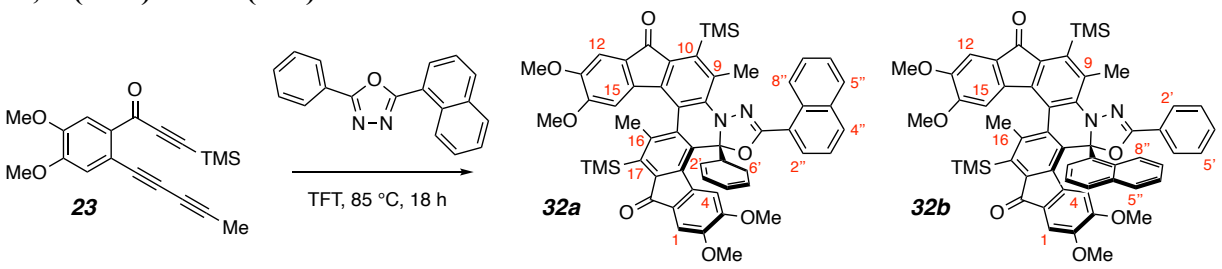
from HSQC, from HMBC, from NOESY

IR (neat): 2998, 2935, 2899, 2835, 1703, 1456, and 1021 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{54}H_{55}O_9Si_2^+$, 931.3441; found, 931.3417.

mp: 302–306 °C.

(±)-2,3,13,14-Tetramethoxy-9,16-dimethyl-6-(naphthalen-1-yl)-4d-phenyl-10,17-bis(trimethylsilyl)-11*H*-diindeno[1,2-*a*:1',2'-*i*][1,3,4]oxadiazolo[3,2-*f*]phenanthridine-11,18(4d*H*)-dione (32a)
and
(±)-2,3,13,14-Tetramethoxy-9,16-dimethyl-4d-(naphthalen-1-yl)-6-phenyl-10,17-bis(trimethylsilyl)-11*H*-diindeno[1,2-*a*:1',2'-*i*][1,3,4]oxadiazolo[3,2-*f*]phenanthridine-11,18(4d*H*)-dione (32b)



In a threaded culture tube, 2-(naphthalen-1-yl)-5-phenyl-1,3,4-oxadiazole[6] (42 mg, 0.15 mmol, 1 equiv) was added to a solution of triyne **23** (50 mg, 0.15 mmol, 1 equiv) in α,α,α-trifluorotoluene (5 mL). The tube was closed with a Teflon-lined screw cap, and the solution was heated at 90 °C for 18 h. The solvent was removed and the residue was purified by MPLC (4:1 hex:EtOAc) to afford to afford **32a** and **32b** (22 mg, 0.024 mmol, 31% combined yield) as a 5.7:1 mixture of co-eluting regioisomers. This sample of the mixture of regioisomers appeared as an orange, amorphous crystalline solid.

A crystalline sample of **32a** for attempted X-ray diffraction analysis was prepared by vapor diffusion at room temperature using a dichloromethane and hexanes solvent system. The analysis was supportive of the structure assigned as **32a** on the basis of the NMR analysis below, although the presence of multiple solvent molecules in the crystal compromised the data and its analysis, rendering the results to be of deemed not fully suitable for publication.

Data for the major isomer (32a), extracted from the spectra of the mixture:

^{1}H-NMR (400 MHz, $CDCl_3$): δ 9.20 (d, *J* = 8.7 Hz, 1H, *H8"*), 7.88–7.83 (m, 2H, *H5"*, *H4"*), 7.71 (dd, *J* = 7.4, 1.1 Hz, 1H, *H2"*), 7.67–7.62 (nfod, J_{app} = 8.1 Hz, 2H, *H2'/6'*), 7.60 (ddd, *J* = 8.4, 6.9, 1.4 Hz, 1H, *H7"*), 7.53 (ddd, *J* = 8.1, 6.9, 1.1 Hz, 1H, *H6"*), 7.37–7.30 (m, 4H, *H3'/5'*, *H4'*, and *H3"*), 7.20 (s, 1H, *H1*), 7.13 (s, 1H, *H12*), 7.05 (s, 1H, *H4*), 6.80 (s, 1H, *H15*), 3.95 (s, 3H, C2OCH_3), 3.91 (s, 3H, C13OCH_3), 3.73 (s, 3H, C14OCH_3), 3.44 (s, 3H, C3OCH_3), 2.67 (s, 3H, C9CH_3), 2.47 (s, 3H, C16CH_3), 0.48 [s, 9H, C10Si(CH_3)$_3$], and 0.43 [s, 9H, C17Si(CH_3)$_3$].

^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ 194.3 (C18), 193.5 (C11), 153.9 (C14), 153.8 (C3), 150.9 (C6), 149.9 (C13), 149.5 (C2), 143.9, 142.74, 142.72, 141.8, 141.7, 139.9, 139.4, 139.3, 138.9, 138.8, 137.8, 136.9, 135.1, 134.9, 133.9, 131.6, 130.2, 130.1, 129.1, 128.9, 127.9, 127.6, 127.5, 127.3, 126.6, 126.40, 126.39, 125.1, 123.0, 121.4, 109.5 (C4), 106.7 (C12), 106.2 (C1), 104.5 (C15), 98.2 (C4d), 56.5 (C14OCH_3), 56.32 (C2OCH_3 or C13OCH_3), 56.29 (C2OCH_3 or C13OCH_3), 56.1 (C3OCH_3), 24.6 (C16CH_3), 20.3 (C9CH_3), 3.5 [C17Si(CH_3)$_3$], and 2.4 [C10Si(CH_3)$_3$].

from HSQC, from HMBC, from NOESY

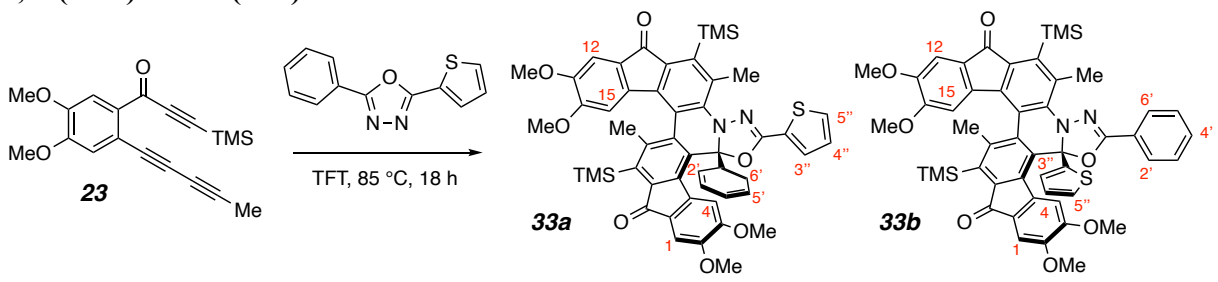
Partial data for the minor isomer (32b), extracted from the spectra of the mixture:

^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.44 (d, *J* = 8.5 Hz, 1H, *H8"*), 7.14 (s, 1H, *H1* or *H12*), 7.11 (s, 1H, *H1* or *H12*), 6.82 (s, 1H, *H15*) 6.68 (s, 1H, *H4*), 3.90 (s, 3H, C2OCH_3 or C13OCH_3), 3.89 (s, 3H, C2OCH_3 or C13OCH_3), 3.76 (s, 3H, C14OCH_3), 2.85 (s, 3H, C3OCH_3), 2.49 (s, 3H, C16CH_3), 2.45 (s, 3H, C9CH_3), 0.45 [s, 9H, C10Si(CH_3)$_3$ or C17Si(CH_3)$_3$], and 0.39 [s, 9H, C10Si(CH_3)$_3$ or C17Si(CH_3)$_3$].

IR (neat): 3058, 3002, 2938, 2900, 2835, 1706, 1493, and 1022 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H^+]: calcd for $C_{56}H_{53}N_2O_7Si_2^+$, 921.3386; found, 921.3363.

(±)-2,3,13,14-Tetramethoxy-9,16-dimethyl-4d-phenyl-6-(thiophen-2-yl)-10,17-bis(trimethylsilyl)-11*H*-diindeno[1,2-*a*:1',2'-*i*][1,3,4]oxadiazolo[3,2-*f*]phenanthridine-11,18(4d*H*)-dione (33a)
and
(±)-2,3,13,14-Tetramethoxy-9,16-dimethyl-6-phenyl-4d-(thiophen-2-yl)-10,17-bis(trimethylsilyl)-11*H*-diindeno[1,2-*a*:1',2'-*i*][1,3,4]oxadiazolo[3,2-*f*]phenanthridine-11,18(4d*H*)-dione (33b)



In a threaded culture tube, 2-phenyl-5-(thiophen-2-yl)-1,3,4-oxadiazole[5] (11 mg, 0.048 mmol, 0.75 equiv) was added to a solution of triyne **23** (21 mg, 0.065 mmol, 1 equiv) in α,α,α-trifluorotoluene (2 mL). The tube was closed with a Teflon®-lined screw cap, and the solution was heated at 90 °C for 18 h. The solvent was removed and the residue was purified by MPLC (3:1 hex:EtOAc) to afford **33a** and **33b** (11 mg, 0.013 mmol, 39% combined yield) as an ca. one-to-one mixture of co-eluting regioisomers. The mixture of regioisomers appeared as an orange, amorphous crystalline solid.

Data for the ~1:1 mixture of constitutional isomers 33a and 33b

^{1}H-NMR (400 MHz, $CDCl_3$) (simple line listing with no assignments): δ 7.65–7.60 (m, 4H), 7.42 (dd, *J* = 1.2, 5.0 Hz, 1H), 7.40–7.29 (m, 8H), 7.22 (dd, *J* = 1.2, 3.7 Hz, 1H), 7.20 (s, 1H), 7.16 (s, 1H), 7.12 (s, 1H), 7.21 (s, 1H), 7.07 (dd, *J* = 1.2, 3.7 Hz, 1H), 6.98 (dd, *J* = 3.7, 5.0 Hz, 1H), 6.96 (s, 1H), 6.84 (dd, *J* = 3.7, 5.0 Hz, 1H), 6.77 (s, 1H), 6.71 (s, 1H), 3.96 (s, 3H), 3.93 (s, 3H), 3.90 (s, 3H), 3.90 (s, 3H), 3.72 (s, 3H), 3.69 (s, 3H), 3.66 (s, 3H), 3.49 (s, 3H), 2.61 (s, 3H), 2.53 (s, 3H), 2.45 (s, 3H), 2.44 (s, 3H), 0.46 (s, 9H), 0.44 (s, 9H), 0.43 (s, 9H), and 0.43 (s, 9H).

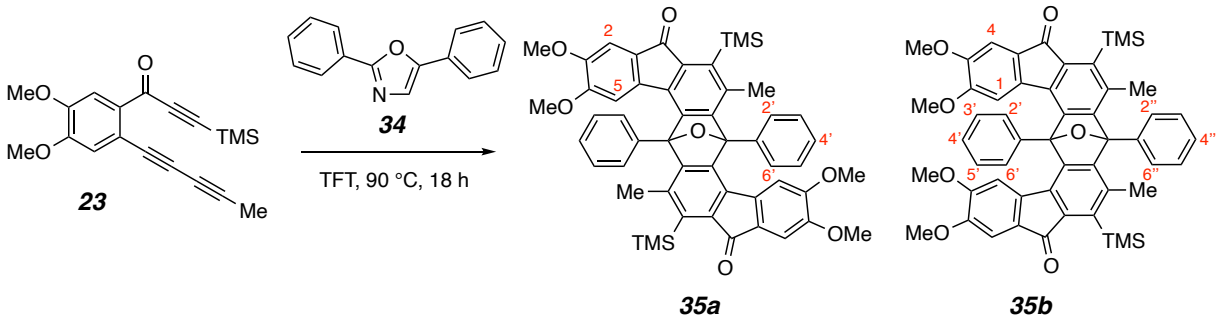
^{1}H-NMR (400 MHz, $CDCl_3$) (line listing with assignments): δ 7.65–7.60 (m, 4H, *H2a'/6a'* and *H2b'/6b'*), 7.42 (dd, *J* = 1.2, 5.0 Hz, 1H, *H5a"* or *H5b"*), 7.40–7.29 (m, 8H, *H3a'*, *H3b'*, *H4a'*, *H4b'*, *H5a'*, *H5b'*, [one of *H1a*, *H1b*, *H12a*, *H12b*, *H15a*, or *H15b*], and [one of *H5a"* or *H5b"*]), 7.22 (dd, *J* = 1.2, 3.7 Hz, 1H, *H3a"* or *H3b"*), 7.20 (s, 1H, *H1a*, *H1b*, *H12a*, *H12b*, *H15a*, or *H15b*), 7.16 (s, 1H, *H1a*, *H1b*, *H12a*, *H12b*, *H15a*, or *H15b*), 7.12 (s, 1H, *H1a*, *H1b*, *H12a*, *H12b*, *H15a*, or *H15b*), 7.21 (s, 1H, *H1a*, *H1b*, *H12a*, *H12b*, *H15a*, or *H15b*), 7.07 (dd, *J* = 1.2, 3.7 Hz, 1H, *H3a"* or *H3b"*), 6.98 (dd, *J* = 3.7, 5.0 Hz, 1H, *H4a"* or *H4b"*), 6.96 (s, 1H, *H1a*, *H1b*, *H12a*, *H12b*, *H15a*, or *H15b*), 6.84 (dd, *J* = 3.7, 5.0 Hz, 1H, *H4a"* or *H4b"*), 6.77 (s, 1H, *H4a* or *H4b*), 6.71 (s, 1H, *H4a* or *H4b*), 3.96 (s, 3H, -OCH_3), 3.93 (s, 3H, -OCH_3), 3.90 (s, 3H, -OCH_3), 3.90 (s, 3H, -OCH_3), 3.72 (s, 3H, -OCH_3), 3.69 (s, 3H, -OCH_3), 3.66 (s, 3H, -OCH_3), 3.49 (s, 3H, -OCH_3), 2.61 (s, 3H, Ar-CH_3), 2.53 (s, 3H, Ar-CH_3), 2.45 (s, 3H, Ar-CH_3), 2.44 (s, 3H, Ar-CH_3), 0.46 [s, 9H, Si(CH_3)$_3$], 0.44 [s, 9H, Si(CH_3)$_3$], 0.43 [s, 9H, Si(CH_3)$_3$], and 0.43 [s, 9H, Si(CH_3)$_3$].

$^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$) (requires 88 resonances; 83 uniquely identified): δ 194.3, 194.1, 193.51, 193.50, 153.9 (2x), 153.7, 153.6, 151.4, 149.9 (2x), 149.6, 149.4, 148.1, 144.0, 143.9, 143.1, 142.9, 142.8, 142.4, 141.79, 141.75, 141.73, 141.68, 140.0, 139.5, 139.37, 139.36, 139.34, 139.31, 139.2, 139.1, 138.2, 137.8, 137.6, 137.2, 137.1, 134.8, 134.4, 129.9, 129.6, 129.0, 128.9, 128.7, 128.5, 128.0, 127.79, 127.78, 127.6, 127.21, 127.18, 127.07, 127.05, 126.4, 125.3, 123.2, 123.0, 109.65, 109.60, 106.68, 106.66, 106.1, 106.0, 104.4 (2x), 100.2, 97.3, 56.5, 56.4, 56.32, 56.29, 56.28, 56.27, 56.20, 56.0, 24.7, 24.6, 20.05, 20.04, 3.50 (2x), 2.32, and 2.31.

IR (neat): 3081, 3000, 2934, 2900, 2835, 1706, 1493, and 1023 cm^{-1}.

HRMS (ESI-TOF) *m/z* [$M+H^+$]: calcd for $C_{50}H_{49}N_2O_7SSi_2^+$, 877.2794; found, 877.2770.

(±)-3,4,11,12-Tetramethoxy-7,15-dimethyl-6,14-diphenyl-8,16-bis(trimethylsilyl)-6,14-dihydro-6,14-epoxydiindeno[1,2-*a*:1',2'-*h*]anthracene-1,9-dione (35a)
and
2,3,13,14-Tetramethoxy-7,9-dimethyl-8,16-diphenyl-6,10-bis(trimethylsilyl)-8,16-dihydro-8,16-epoxydiindeno[1,2-*a*:2',1'-*j*]anthracene-5,11-dione (35b)



In a threaded culture tube charged with 4 Å molecular sieves, 2,5-diphenyloxazole (**34**, 20 mg, 0.93 mmol, 0.75 equiv) was added to a solution of the triyne **23** (40 mg, 0.12 mmol, 1 equiv) in α,α,α-trifluorotoluene (4 mL). The tube was closed with a Teflon®-lined screw cap, and the solution was heated at 90 °C for 18 h. The solvent was removed and the residue was purified by MPLC (5:1 hex:EtOAc) to afford **35a** (27 mg, 0.032 mmol, 52%) and **35b** (8 mg, 0.010 mmol, 15%), each as a yellow crystalline solids.

Data for 35a (the S isomer)

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.91–7.85 (m, 4H, *H2'* and *H6'*), 7.58–7.51 (nfom, 2H, *H4'*), 7.49–7.42 (m, 4H, *H3'* and *H5'*), 7.13 (s, 2H, *H2*), 6.44 (s, 2H, *H5*), 3.88 (s, 6H, C3OCH_3), 3.25 (s, 6H, C4OCH_3), 2.38 (s, 6H, Ar-CH_3), and 0.43 [s, 18H, Si(CH_3)$_3$].

^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ 193.4 (C1), 153.2 (C4), 152.9 (C6a), 149.3 (C3), 143.4, 142.7, 141.5, 137.9, 137.4, 134.7, 134.6, 132.3, 130.5, 130.0, 129.1, 128.8, 128.2, 109.8 (C5), 106.4 (C2), 93.2 (C6), 56.2 (C3-OCH_3), 55.5 (C6-OCH_3), 24.8 (C7-CH_3), and 2.9 [C8-Si(*C*H_3)$_3$].

Slow rotation about the C6–Ph bond is evidenced by broadening in the proton spectrum and identifiable additional distinct resonances in the carbon spectrum (higher coalescence temperature), seen also in the HSQC spectrum.

from HSQC, from HMBC, from NOESY

IR (neat): 3000, 2956, 2937, 2899, 2933, 1705, 1495, and 1024 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{52}H_{51}O_7Si_2^+$, 843.3168; found, 843.3154.

mp: 332–345 °C (with decomposition).

Data for 35b [the (achiral) U isomer]

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.98–7.94 (nfod, 2H, J_{app} = 8.2 Hz, *H2'/6'*), 7.74–7.70 (nfod, 2H, J_{app} = 8.4 Hz, *H2''/6''*), 7.51–7.44 (m, 5H, *H3'/3''* and *H4''* or *H4'*), 7.41 (tt, *J* = 7.4, 1.3 Hz, and *H4''* or *H4'*), 7.15 (s, 2H, *H4*), 6.81 (s, 2H, *H1*), 3.85 (s, 6H, C3OCH_3), 3.49 (s, 6H, C2OCH_3), 2.35 (s, 6H, Ar-CH_3), and 0.44 [s, 18H, Si(CH_3)$_3$].

^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ 193.4 (C5), 153.7 (C2), 152.3 (C7a), 150.8 (C3), 143.8 (C6), 143.3, 141.7, 137.6, 137.4 (C7), 135.3, 135.2, 135.1, 131.8 (C2'/6'), 130.7 (C2''/6''), 130.3, 129.6, 129.2, 129.1, 128.5, 114.8 (C1), 107.2 (C4), 93.8 (C8), 92.7 (C16), 58.5 (C2-OCH_3), 56.1 (C2-OCH_3), 24.5 (ArCH_3), and 3.2 [Si(CH_3)$_3$].

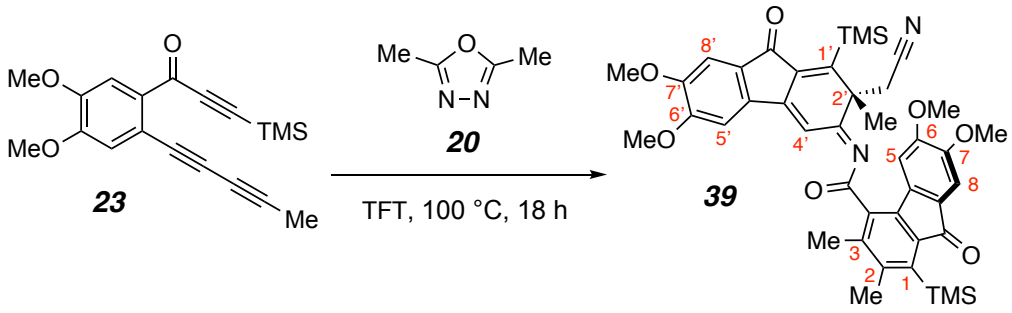
from HSQC, from HMBC, from NOESY

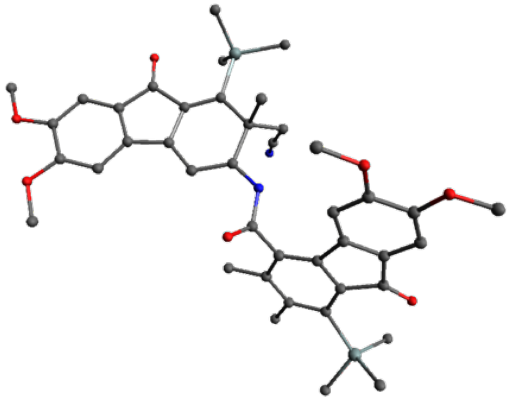
IR (neat): 3061, 2974, 2940, 2899, 2837, 1703, 1491, and 1024 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{52}H_{51}O_7Si_2^+$, 843.3168; found, 843.3147.

mp: 316–320 °C (with decomposition).

(±)-(*E*)-*N*-(2-(Cyanomethyl)-6,7-dimethoxy-2-methyl-9-oxo-1-(trimethylsilyl)-2,9-dihydro-3*H*-fluoren-3-ylidene)-6,7-dimethoxy-2,3-dimethyl-9-oxo-1-(trimethylsilyl)-9*H*-fluorene-4-carboxamide (39)





from the X-ray diffraction co-ordinates

In a threaded culture tube, 2,5-dimethyl-1,3,4-oxadiazole[7](**20**, 11 mg, 0.12 mmol, 0.75 equiv) was added to a solution of triyne **23** (50 mg, 0.15 mmol, 1 equiv) in α,α,α-trifluorotoluene (5 mL). The tube was closed with a Teflon®-lined screw cap, and the solution was heated at 100 °C for 18 h. The solvent was removed and the residue was purified by MPLC (1.5:1 hex:EtOAc) to afford **39** (16 mg, 0.021 mmol, 28%) as a yellow crystalline solid.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.38 (s, 1H, *H5′*), 7.28 (s, 1H, *H8*), 7.18 (s, 1H, *H8′*), 6.95 (s, 1H, *H4′*), 6.81 (s, 1H, *H5*), 3.99 (s, 3H, C7OCH_3), 3.93 (s, 3H, C6'OCH_3), 3.92 (s, 3H, C7'OCH_3), 3.90 (s, 3H, C6OCH_3), 3.37 (d, J = 16.8, 1H, CH_aH$_b$CN), 3.06 (d, J = 16.7, 1H, CH$_a$$H_b$CN), 2.38 (s, 3H, C3C$H_3$), 2.34 (s, 3H, C2C$H_3$), 1.55 (s, 3H, C2'C$H_3$), 0.48 [s, 9H, C1'Si(C$H_3$)$_3$], and 0.42 [s, 9H, C1Si(CH_3)$_3$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 193.7 (C9'), 188.5 (C9), 184.1 (NC=O), 172.4 (C=N), 161.5 (C1'), 156.0 (C6), 154.1 (C7), 153.7 (C6'), 149.4 (C7'), 145.9, 143.9, 143.1 (Cl), 139.4, 139.2, 137.8, 137.7, 137.4, 136.6, 134.0, 132.8, 127.5, 117.0 (C≡N), 107.8 (C4'), 106.6 (C8'), 106.4 (C5'), 104.7 (C8), 103.2 (C5), 56.5 (2x), 56.4, 56.1, 50.1 (C2'), 28.25 (C_{sp3}CH$_3$), 28.22 (CH$_2$-CN), 21.7 (C2), 19.1 (C3), 2.8 (C1), and 2.3 (C1').

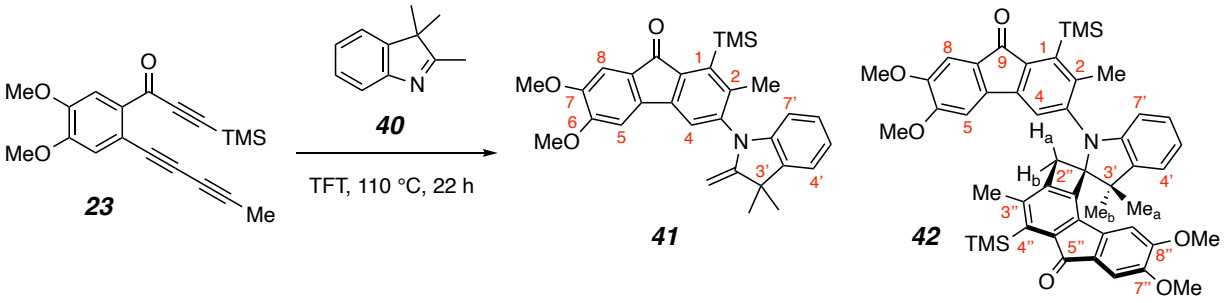
from HSQC, from HMBC, from NOESY

IR (neat): 3005, 2939, 2900, 2835, 1704, 1494, 1074, and 1006 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{42}H_{46}N_2O_7Si_2^+$, 747.2916; found, 747.2900.

mp: 204–208 °C.

3-(3,3-Dimethyl-2-methyleneindolin-1-yl)-6,7-dimethoxy-2-methyl-1-(trimethylsilyl)-9*H*-fluoren-9-one (41)
and
(±)-1'-(6,7-Dimethoxy-2-methyl-9-oxo-1-(trimethylsilyl)-9*H*-fluoren-3-yl)-7,8-dimethoxy-3,3',3'-trimethyl-4-(trimethylsilyl)spiro[cyclobuta[*c*]fluorene-1,2'-indolin]-5(2*H*)-one (42)



In a threaded culture tube, 2,3,3-trimethyl-3*H*-indole (**40**, 15 mg, 0.094 mmol, 0.75 equiv) was added to a solution of triyne **23** (40 mg, 0.12 mmol, 1 equiv) in α,α,α-trifluorotoluene (4 mL). The tube was closed with a Teflon®-lined screw cap, and the solution was heated at 110 °C for 22 h. The solvent was removed and the residue was purified by MPLC (5:1 hex:EtOAc) to afford, in order of elution, **41** (20 mg, 44%) and **42** (15 mg, 30%), each as an orange, amorphous solid.

Data for 41

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.26 (s, 1H, *H4*), 7.20 (ddd, *J* = 7.3, 1.3, 0.6 Hz, 1H, *H4'*), 7.16 (s, 1H, *H8*), 7.07 (ddd, *J* = 7.6, 7.6, 1.3 Hz, 1H, *H6'*), 6.89 (s, 1H, *H5*), 6.85 (ddd, *J* = 7.4, 7.4, 1.0 Hz, 1H, *H5'*), 6.30 (ddd, *J* = 7.8, 0.8, 0.8 Hz, 1H, *H7'*), 3.95 (s, 3H, C6OCH_3), 3.94 (d, *J* = 1.8, 1H, =CH_aH$_b$), 3.92 (s, 3H, C7OCH_3), 3.69 (d, *J* = 1.8, 1H, =CH$_a$$H_b$), 2.19 (s, 3H, C2C$H_3$), 1.51 (s, 3H, C3'C$H_3$), 1.46 (s, 3H, C3'C$H_3$), and 0.46 [s, 9H, C1Si(CH_3)$_3$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 194.1 (C9), 161.4 (C2'), 154.7 (C6), 149.8 (C7), 145.8 (C7'a), 144.1, 144.2, 143.4, 141.0, 140.4, 138.6, 137.7, 127.8 (C6'), 126.8, 122.4 (C4'), 120.7 (C4), 119.6 (C5'), 107.0 (C8), 106.8 (C7'), 103.0 (C5), 76.7 (=CH_2), 56.5 (C6-OCH_3), 56.4 (C7-OCH_3), 44.6 (C3'), 31.0 (C3'-CH_3), 29.6 (C3'-CH_3), 19.1 (C2-CH_3), and 2.9 [C1-Si(CH_3)$_3$].

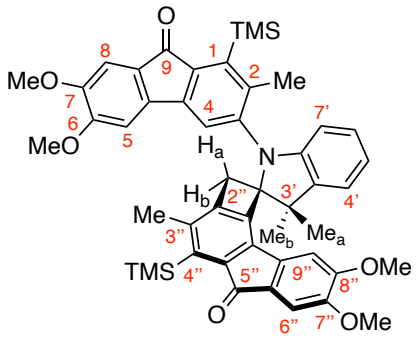
from HSQC, from HMBC

IR (neat): 3103, 3072, 3003, 2960, 2929, 2899, 2863, 2837, 1704, 1588, 1484, 1315, 1244, and 1091 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{30}H_{34}NO_3Si^+$, 484.2302; found, 484.2302.

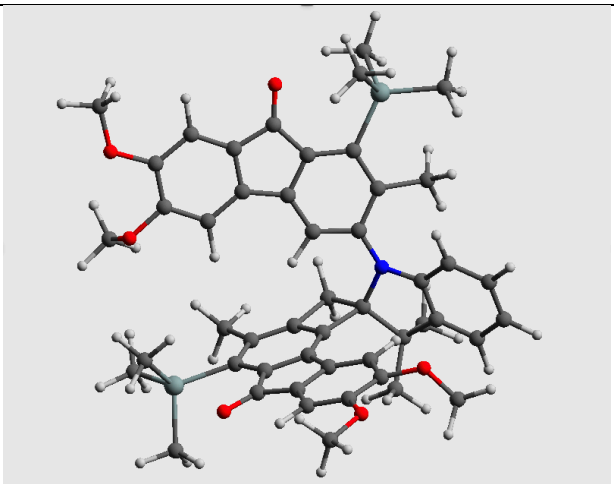
Data for 42 (following page)

Data for 42



nOe's

C3'Me_a <–> H9''	C2Me <–> C1TMS
C8''OMe <–> H9''	C3''Me <–> C1TMS
C3'Me_a <–> H2''b	H7' <–> C2Me
C3'Me_b <–> H2''b	H4' <–> C3'Me_a
H2''a <–> H4	H4' <–> C3'Me_b
H2''a <–> C2Me	H6'' <–> C7''OMe
H2''a <–> C3''Me	H8 <–> C7OMe
H2''b <–> C3''Me	H4 <–> H5
	H5 <–> C6OMe



minimized geometry from molecular mechanics (OPLS_2005)

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.24 (dd, *J* = 7.3, 1.3 Hz, 1H, *H4'*), 7.08 (s, 1H, *H6''*), 7.03 (ddd, *J* = 7.6, 7.6, 1.3 Hz, 1H, *H6'*), 7.01 (s, 1H, *H8*), 6.93 (s, 1H, *H4*), 6.78 (ddd, *J* = 7.4, 7.4, 1.1 Hz, 1H, *H5'*), 6.29 (s, 1H, *H9''*), 6.07 (dd, *J* = 7.8, 1.1 Hz, 1H, *H7'*), 5.95 (s, 1H, *H5*), 3.84 (s, 3H, C7''OCH_3), 3.83 (s, 3H, C7OCH_3), 3.60 (dd, *J* = 15.6, 0.7 Hz, 1H, C2''H_aH_b), 3.57 (s, 3H, C6OCH_3), 3.24 (s, 3H, C8''OCH_3), 3.04 (dd, *J* = 15.5, 0.9 Hz, 1H, C2''H_aH_b), 2.40 (s, 3H, C2CH_3), 2.15 (s, 3H, C3''CH_3), 1.50 (s, 3H, C3'CH_{3b}), 1.37 (s, 3H, C3'CH_{3a}), 0.44 [s, 9H, C1Si(CH_3)$_3$], and 0.34 [s, 9H, C4''Si(CH_3)$_3$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 194.4 (C5''), 194.1 (C9), 154.8 (C8''), 154.6 (C6), 149.6 (C7), 149.4 (C7''), 148.4, 147.4, 144.5, 143.6, 143.2, 142.7, 142.3, 141.5, 140.5, 139.6, 138.6, 137.9, 137.42, 137.39, 137.2, 128.7 (C6'), 127.1, 126.5, 122.4 (C4'), 120.9 (C4), 119.0 (C5'), 107.0 (C7'), 106.8 (C8), 106.5 (C6''), 105.4 (C9''), 101.9 (C5), 83.1 (spiroC), 56.5 (C8''OCH_3), 56.33 (C7OCH_3 or C7''OCH_3), 56.30 (C7OCH_3 or C7''OCH_3), 55.9 (C6O-CH_3), 46.1 (C3'), 36.3 (C2''), 29.4 (C3'CH_{3b}), 23.6 (C3'CH_{3a}), 19.2 (C2CH_3), 19.1 (C3''CH_3), 3.0 (C4''-TMS), and 2.9 (C1-TMS).

from HSQC, from HMBC, from NOESY

IR (neat): 3067, 3003, 2934, 2837, 1705, 1589, 1493, 1311, 1245, and 1088 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H^+]: calcd for $C_{49}H_{54}NO_6Si_2^+$, 808.3484; found, 808.3490.

III. Computational Methods

All DFT calculations were performed using Gaussian 16.[8] Each of the species in Figure 14 was optimized and characterized using a frequency calculation (performed at 298 K) at the M06-2X/6-311+G(d,p) level of theory and a chloroform solvation treatment (IEFPCM). Each of the (larger) species in Figure S1 (and Figure 20) was optimized and characterized using M06-2X/6-31G(d) basis set and a chloroform solvation treatment (IEFPCM). Each of the species in Figure 17 and Figure 18 was optimized and characterized using M06-2X/6-31+G(d,p) basis set and a chloroform solvation treatment (IEFPCM). All the HOMO and LUMO energies presented in Figure 19 were computed for the lowest energy, optimized geometry using M06-2X/6-31+G(d,p) basis set and a chloroform solvation treatment (IEFPCM). All structures were first subjected to a Monte Carlo conformational search in MacroModel (using Maestro) with the OPLS_2005 molecular mechanics (MM) force field within the Schrodinger software suite (Release 2020-4).[9] Each of these MM conformers was then used as the starting geometry for optimization in Gaussian using the DFT methods stated above. The resulting ensemble of conformers for each intermediate on the potential energy surface was checked for convergence and the presence of imaginary frequencies. The energies of unique conformers were then Boltzmann averaged to arrive at the Gibbs energy values given for all minima in the Figures. (A protocol outlining this process and the Python scripts used to streamline the dataflow are available in the literature.[10]) The transitions structures are of a single geometrically unique species and each shows a single imaginary frequency.

Given on the following pages are the Gibbs energy values (in Hartree atomic units) and the Cartesian coordinates for each of the computed structures. A 3D representation (generated in CYLview20) for each of the structures is also shown.

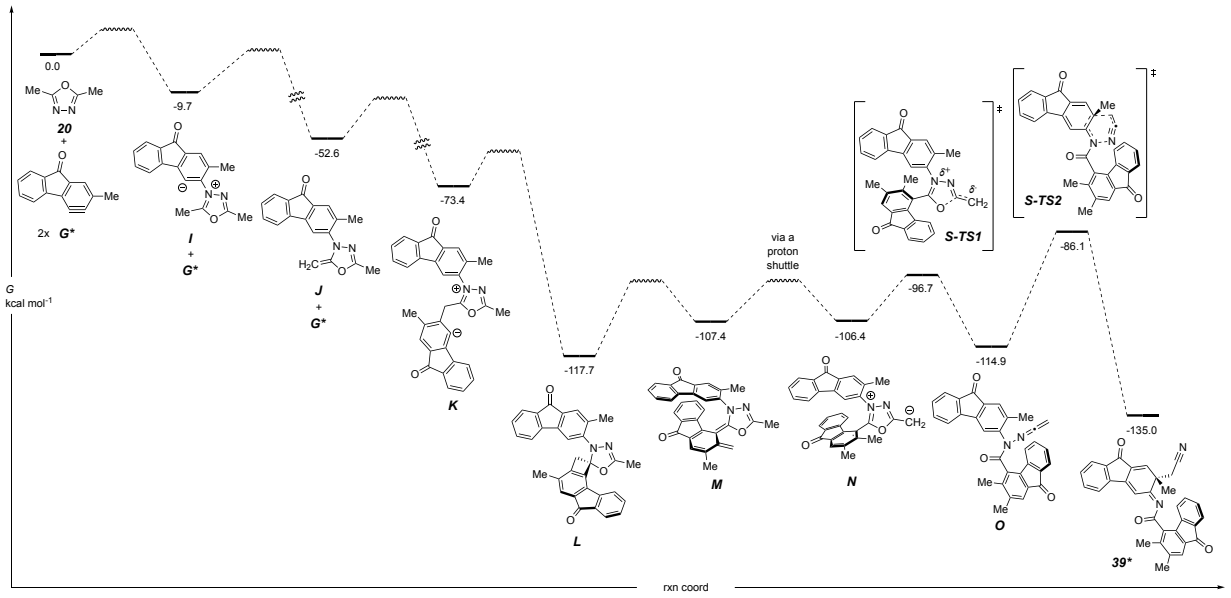
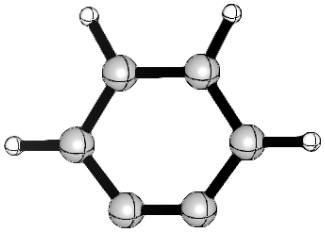


Figure S1. DFT[i] potential energy surface computed starting from the reaction of (two molecules of) the simplified (to reduce conformational complexity) HDDA-benzyne **G*** with 2,5-dimethyl-1,3,4-oxadiazole (**20**) leading to **39***. The energies of the stationary state minima are presented in Figure 20.

[i]IEFPCM(chloroform)/M06-2X/6-31G(d).

Free Energy and Geometry for *o*-benzyne (17):

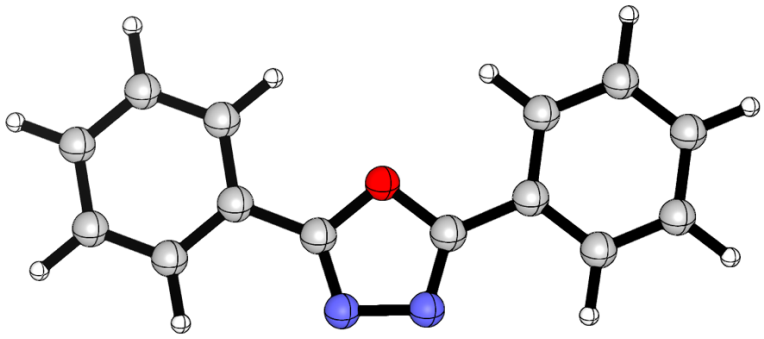


Sum of electronic and thermal free energies: -230.820946 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	1.461709	-0.132351	-0.000000
2	6	0	0.619892	-1.230116	0.000000
3	6	0	-0.619892	-1.230116	0.000000
4	6	0	-1.461709	-0.132351	-0.000000
5	6	0	-0.702510	1.051168	0.000000
6	6	0	0.702510	1.051168	0.000000
7	1	0	2.542861	-0.134123	-0.000000
8	1	0	-2.542861	-0.134123	-0.000000
9	1	0	-1.224396	2.001919	0.000000
10	1	0	1.224396	2.001919	0.000000

Free Energy and Geometry for diphenyl-1,3,4-oxadiazole (24):

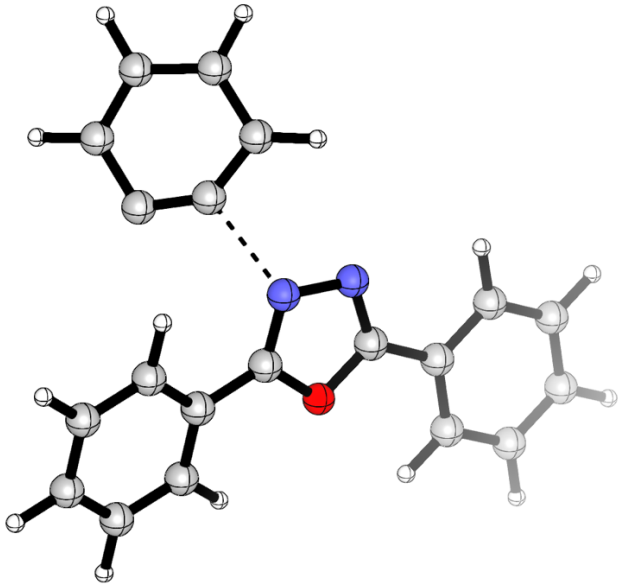


Sum of electronic and thermal free energies: -723.955095 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	7	0	0.691355	-1.911621	-0.001214
2	7	0	-0.691356	-1.911621	-0.000852
3	6	0	-1.061326	-0.673800	-0.000329
4	8	0	0.000000	0.165763	0.000224
5	6	0	1.061327	-0.673801	-0.000284
6	6	0	2.413216	-0.122537	-0.000056
7	6	0	-2.413215	-0.122536	0.000017
8	6	0	2.615819	1.258583	-0.002670
9	6	0	3.910575	1.764069	-0.002617
10	6	0	4.999109	0.897001	0.000047
11	6	0	4.794046	-0.481655	0.002680
12	6	0	3.504889	-0.995013	0.002659
13	6	0	-2.615818	1.258585	0.001834
14	6	0	-3.910574	1.764071	0.002189
15	6	0	-4.999109	0.897002	0.000730
16	6	0	-4.794046	-0.481656	-0.001086
17	6	0	-3.504890	-0.995014	-0.001443
18	1	0	1.765592	1.929520	-0.004779
19	1	0	4.068508	2.835558	-0.004687
20	1	0	6.007078	1.294072	0.000082
21	1	0	5.641041	-1.156675	0.004791
22	1	0	3.331080	-2.064072	0.004729
23	1	0	-1.765591	1.929524	0.002980
24	1	0	-4.068506	2.835561	0.003615
25	1	0	-6.007078	1.294072	0.001002
26	1	0	-5.641043	-1.156678	-0.002229
27	1	0	-3.331080	-2.064074	-0.002860

Free Energy and Geometry for TS1:



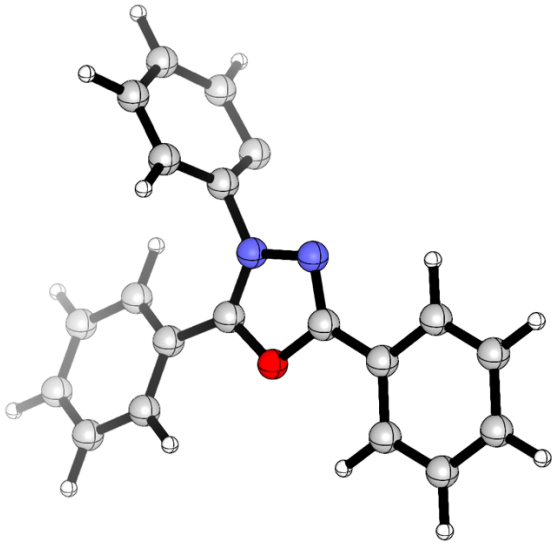
Sum of electronic and thermal free energies: -954.755995 a.u.

Number of imaginary frequencies: 1

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	3.763141	-2.406825	-1.127120
2	6	0	2.865514	-1.392606	-0.732999
3	6	0	1.935611	-1.801518	0.030594
4	6	0	1.562424	-2.990781	0.597374
5	6	0	2.461935	-3.991882	0.205635
6	6	0	3.541557	-3.700239	-0.642554
7	7	0	0.404660	-0.438711	0.655445
8	6	0	0.292120	0.808217	0.314354
9	8	0	-0.993694	1.112491	0.043039
10	6	0	-1.654086	-0.053588	0.247592
11	7	0	-0.853027	-0.998370	0.611527
12	6	0	-3.098783	-0.105178	0.049809
13	6	0	1.320553	1.828705	0.208367
14	6	0	1.039907	3.045577	-0.420027
15	6	0	2.033629	4.008948	-0.520732
16	6	0	3.300663	3.761531	0.003693
17	6	0	3.576281	2.549852	0.631739
18	6	0	2.589711	1.578586	0.737462
19	6	0	-3.800547	1.035150	-0.344651
20	6	0	-5.176205	0.964974	-0.528742
21	6	0	-5.848478	-0.235520	-0.320196

22	6	0	-5.144750	-1.372314	0.073866
23	6	0	-3.771257	-1.312049	0.259607
24	1	0	4.608647	-2.216669	-1.781673
25	1	0	0.709593	-3.159950	1.239874
26	1	0	2.314716	-5.003100	0.567511
27	1	0	4.218508	-4.500063	-0.924005
28	1	0	0.053748	3.228264	-0.829073
29	1	0	1.821545	4.951669	-1.009623
30	1	0	4.073980	4.516133	-0.076472
31	1	0	4.560959	2.360830	1.040766
32	1	0	2.789803	0.634058	1.226026
33	1	0	-3.273095	1.967369	-0.505035
34	1	0	-5.722408	1.848528	-0.835052
35	1	0	-6.920910	-0.286780	-0.464558
36	1	0	-5.668229	-2.306515	0.235426
37	1	0	-3.212386	-2.188380	0.564353

Free Energy and Geometry for 27:



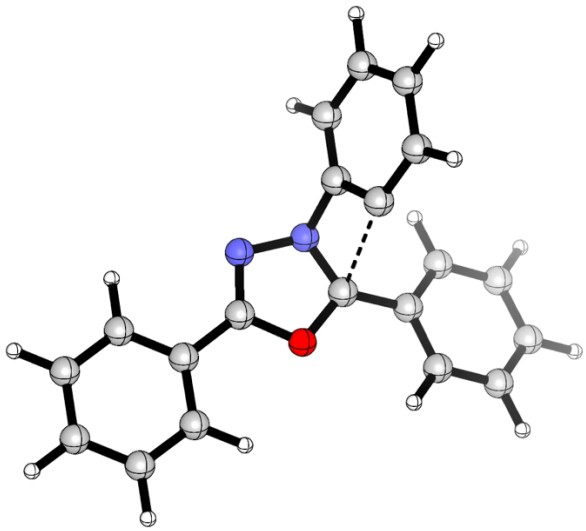
Sum of electronic and thermal free energies: -954.779339 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	3.089840	-2.949034	-1.094405
2	6	0	1.921890	-2.157785	-1.233311
3	6	0	1.548894	-1.631613	-0.005417
4	6	0	2.155149	-1.789072	1.242132
5	6	0	3.301045	-2.569688	1.292574
6	6	0	3.766741	-3.149233	0.109110
7	7	0	0.369034	-0.746531	-0.001003
8	6	0	0.332896	0.560405	-0.040581
9	8	0	-0.948322	0.931628	-0.043949
10	6	0	-1.666619	-0.224396	-0.014298
11	7	0	-0.898936	-1.259742	0.009518
12	6	0	-3.121251	-0.169135	-0.015641
13	6	0	1.384003	1.565211	-0.060361
14	6	0	1.048487	2.865110	0.339058
15	6	0	2.019226	3.854595	0.334293
16	6	0	3.315876	3.554392	-0.076534
17	6	0	3.642586	2.264650	-0.485909
18	6	0	2.684474	1.260244	-0.479547
19	6	0	-3.780299	1.060954	-0.042965
20	6	0	-5.169047	1.089582	-0.045431
21	6	0	-5.891429	-0.099863	-0.021232
22	6	0	-5.227965	-1.325366	0.004872
23	6	0	-3.841806	-1.366245	0.007466
24	1	0	3.506302	-3.432634	-1.977225
25	1	0	1.752712	-1.319329	2.134577

26	1	0	3.817768	-2.725994	2.231880
27	1	0	4.664165	-3.760764	0.134719
28	1	0	0.038421	3.091213	0.657282
29	1	0	1.764971	4.858434	0.650026
30	1	0	4.072574	4.329656	-0.081315
31	1	0	4.648116	2.037079	-0.816277
32	1	0	2.933743	0.261405	-0.812952
33	1	0	-3.212726	1.983115	-0.065102
34	1	0	-5.686323	2.040483	-0.068094
35	1	0	-6.974372	-0.073254	-0.024405
36	1	0	-5.792322	-2.249227	0.021457
37	1	0	-3.313276	-2.311594	0.024169

Free Energy and Geometry for TS2:



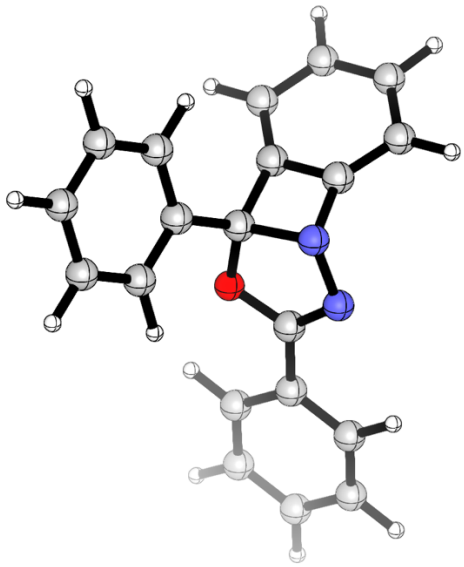
Sum of electronic and thermal free energies: -954.761545 a.u.

Number of imaginary frequencies: 1

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-1.671832	-1.252021	1.114100
2	6	0	-1.356856	-1.664431	-0.192958
3	6	0	-1.907629	-2.732529	-0.885991
4	6	0	-2.866162	-3.484340	-0.212701
5	6	0	-3.255374	-3.116018	1.076984
6	6	0	-2.692403	-2.004317	1.712569
7	7	0	-0.378068	-0.767089	-0.739748
8	6	0	-0.465127	0.432588	-0.108533
9	8	0	0.778097	0.856832	0.118222
10	6	0	1.601335	-0.177288	-0.271784
11	7	0	0.951773	-1.159481	-0.772419
12	6	0	3.040893	-0.027735	-0.095267
13	6	0	-1.541410	1.416752	-0.148808
14	6	0	3.891117	-1.034039	-0.561817
15	6	0	5.260948	-0.905154	-0.388958
16	6	0	5.783688	0.222147	0.243228
17	6	0	4.934113	1.222758	0.704263
18	6	0	3.559540	1.102955	0.536897
19	6	0	-1.401421	2.607351	0.566804
20	6	0	-2.408305	3.562222	0.510223
21	6	0	-3.541842	3.337491	-0.265353
22	6	0	-3.668775	2.154076	-0.991751
23	6	0	-2.674153	1.190236	-0.936672
24	1	0	-1.613162	-2.964895	-1.903022
25	1	0	-3.318543	-4.342432	-0.695106

26	1	0	-4.003342	-3.710297	1.592679
27	1	0	-3.042107	-1.752746	2.710888
28	1	0	3.472207	-1.904446	-1.051852
29	1	0	5.923064	-1.683337	-0.747705
30	1	0	6.854485	0.318953	0.375763
31	1	0	5.340341	2.098001	1.195745
32	1	0	2.893932	1.877907	0.895974
33	1	0	-0.519181	2.773947	1.172508
34	1	0	-2.306757	4.482334	1.072216
35	1	0	-4.325480	4.084161	-0.307701
36	1	0	-4.546074	1.983252	-1.603262
37	1	0	-2.772160	0.266721	-1.494583

Free Energy and Geometry for 28:



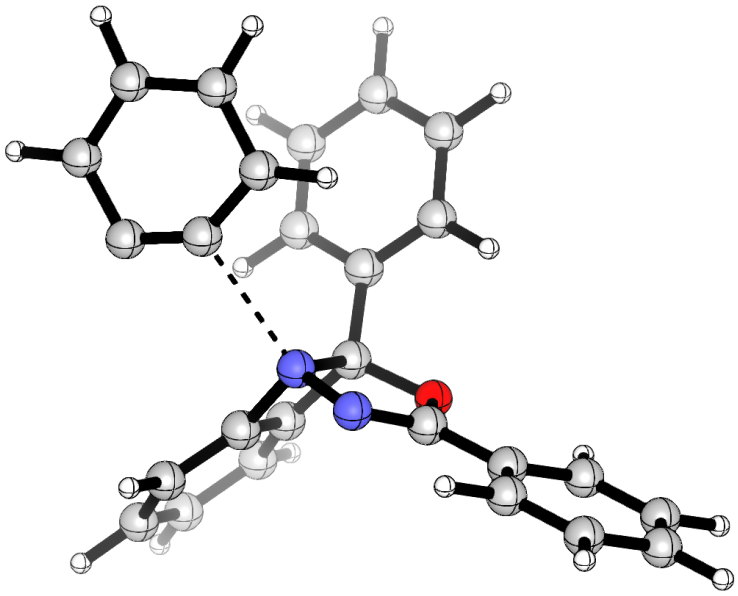
Sum of electronic and thermal free energies: -954.827097 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	1.433900	1.307054	0.516460
2	6	0	1.081559	1.861925	-0.700680
3	6	0	1.292102	3.183292	-1.035635
4	6	0	1.915567	3.934136	-0.030816
5	6	0	2.298924	3.380010	1.195973
6	6	0	2.074324	2.031905	1.502417
7	7	0	0.581394	0.633582	-1.290245
8	6	0	0.890337	-0.037376	0.063307
9	8	0	-0.403880	-0.371433	0.552843
10	6	0	-1.306043	0.079091	-0.365034
11	7	0	-0.842011	0.644354	-1.408614
12	6	0	-2.724504	-0.154778	-0.068077
13	6	0	1.774085	-1.249028	0.016653
14	6	0	-3.696402	0.233203	-0.994595
15	6	0	-5.037865	0.019783	-0.714067
16	6	0	-5.415324	-0.580236	0.486992
17	6	0	-4.447158	-0.966979	1.407613
18	6	0	-3.099634	-0.756803	1.133250
19	6	0	1.218165	-2.507563	-0.217917
20	6	0	2.040102	-3.623511	-0.318299
21	6	0	3.420248	-3.490338	-0.185385
22	6	0	3.975897	-2.236894	0.048281
23	6	0	3.154892	-1.117610	0.149616
24	1	0	1.006713	3.616978	-1.984901

25	1	0	2.114963	4.984243	-0.209836
26	1	0	2.780637	4.017452	1.927471
27	1	0	2.373043	1.611041	2.454569
28	1	0	-3.388932	0.696636	-1.923956
29	1	0	-5.791859	0.319675	-1.431561
30	1	0	-6.464194	-0.745695	0.702462
31	1	0	-4.739136	-1.433278	2.340633
32	1	0	-2.340210	-1.054513	1.845117
33	1	0	0.144163	-2.612264	-0.315289
34	1	0	1.603700	-4.598455	-0.499487
35	1	0	4.059174	-4.362062	-0.261737
36	1	0	5.048495	-2.128257	0.154827
37	1	0	3.589770	-0.141302	0.330610

Free Energy and Geometry for TS3:



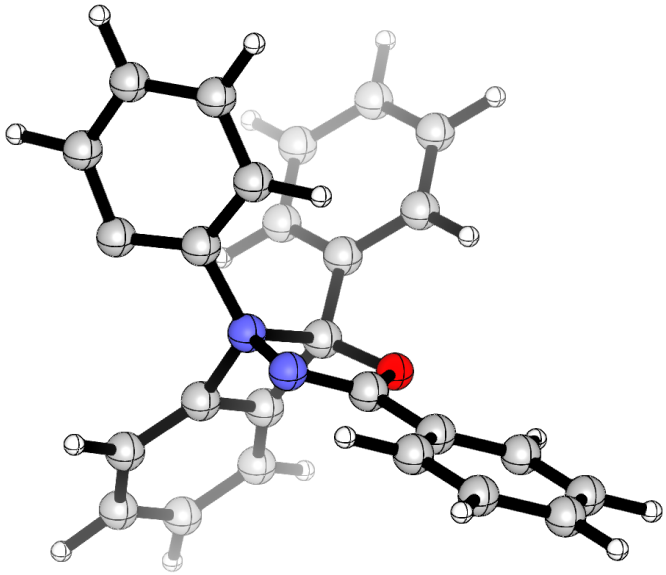
Sum of electronic and thermal free energies: -1185.634272 a.u.

Number of imaginary frequencies: 1

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	0.806770	4.017589	-1.483077
2	6	0	0.554971	2.747900	-2.018242
3	6	0	0.270330	1.769332	-1.086308
4	6	0	0.273856	2.020286	0.273549
5	6	0	0.533065	3.252521	0.834658
6	6	0	0.792725	4.258869	-0.104364
7	7	0	0.040364	0.648871	0.676778
8	6	0	-0.046981	0.306570	-0.825860
9	8	0	-1.413189	-0.062735	-0.975737
10	6	0	-1.993331	0.034857	0.252819
11	7	0	-1.255621	0.421907	1.219954
12	6	0	-3.410487	-0.333868	0.346359
13	6	0	-4.059777	-0.268350	1.582388
14	6	0	-5.400439	-0.611789	1.673019
15	6	0	-6.096619	-1.021237	0.536046
16	6	0	-5.449012	-1.086591	-0.693144
17	6	0	-4.104490	-0.744195	-0.792384
18	6	0	0.868524	-0.785220	-1.295458
19	6	0	0.433688	-2.109775	-1.305477

20	6	0	1.324062	-3.131544	-1.619955
21	6	0	2.650191	-2.834838	-1.919440
22	6	0	3.083361	-1.511508	-1.916171
23	6	0	2.194262	-0.488134	-1.610107
24	6	0	2.178783	-0.104233	1.614222
25	6	0	2.058291	-1.462330	1.729288
26	6	0	3.342960	-2.006797	1.890814
27	6	0	4.490860	-1.195690	1.916526
28	6	0	4.420028	0.197945	1.789219
29	6	0	3.126848	0.716186	1.612826
30	1	0	1.021475	4.841471	-2.152918
31	1	0	0.574109	2.569525	-3.086089
32	1	0	0.539718	3.439886	1.899911
33	1	0	1.001659	5.262091	0.248096
34	1	0	-3.506573	0.051190	2.456959
35	1	0	-5.905360	-0.561026	2.629884
36	1	0	-7.143919	-1.288591	0.610816
37	1	0	-5.989249	-1.404040	-1.576588
38	1	0	-3.593363	-0.791345	-1.745636
39	1	0	-0.597290	-2.341336	-1.065661
40	1	0	0.981881	-4.159608	-1.626804
41	1	0	3.344291	-3.632320	-2.157111
42	1	0	4.115131	-1.275681	-2.147679
43	1	0	2.536747	0.540164	-1.587346
44	1	0	1.152452	-2.051974	1.695442
45	1	0	3.445216	-3.081678	1.993293
46	1	0	5.460365	-1.668181	2.034726
47	1	0	5.320396	0.802144	1.815002

Free Energy and Geometry for 29:



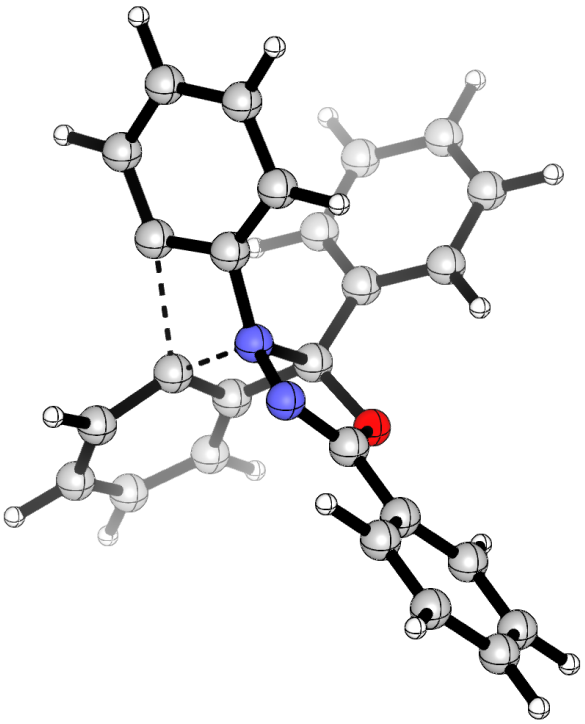
Sum of electronic and thermal free energies: -1185.661593 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	0.695216	4.071946	-1.360095
2	6	0	0.545689	2.810400	-1.934762
3	6	0	0.448275	1.767898	-1.027295
4	6	0	0.513571	1.975569	0.327356
5	6	0	0.649641	3.204069	0.936306
6	6	0	0.740487	4.261523	0.030927
7	7	0	0.307397	0.561262	0.708500
8	6	0	0.260422	0.278261	-0.891665
9	8	0	-1.066955	-0.167575	-1.042234
10	6	0	-1.711760	-0.041266	0.139609
11	7	0	-1.035178	0.328225	1.161911
12	6	0	-3.139714	-0.366379	0.155355
13	6	0	-3.843184	-0.306205	1.361578
14	6	0	-5.194223	-0.617799	1.379566
15	6	0	-5.841758	-0.987952	0.201483
16	6	0	-5.138602	-1.046643	-0.997744
17	6	0	-3.784177	-0.736439	-1.025968
18	6	0	1.254363	-0.691563	-1.424851
19	6	0	0.867360	-1.979514	-1.793237
20	6	0	1.825782	-2.885950	-2.232097
21	6	0	3.165166	-2.513105	-2.287253
22	6	0	3.549895	-1.228061	-1.912503
23	6	0	2.596462	-0.313034	-1.486211

24	6	0	1.354962	-0.114947	1.541300
25	6	0	1.125133	-1.477821	1.752065
26	6	0	2.092166	-2.181511	2.451120
27	6	0	3.225502	-1.497559	2.905449
28	6	0	3.373281	-0.135844	2.654956
29	6	0	2.436430	0.649397	1.934802
30	1	0	0.781720	4.939004	-2.003572
31	1	0	0.508014	2.671046	-3.007100
32	1	0	0.706908	3.336659	2.006034
33	1	0	0.865593	5.267289	0.413064
34	1	0	-3.326351	-0.018179	2.268666
35	1	0	-5.744344	-0.572867	2.311147
36	1	0	-6.897550	-1.230337	0.220179
37	1	0	-5.643796	-1.333371	-1.911575
38	1	0	-3.229617	-0.777368	-1.954891
39	1	0	-0.174673	-2.268605	-1.741052
40	1	0	1.526357	-3.884779	-2.525008
41	1	0	3.910965	-3.224427	-2.621530
42	1	0	4.592906	-0.939218	-1.948798
43	1	0	2.892952	0.682826	-1.176419
44	1	0	0.230799	-1.977075	1.390429
45	1	0	1.967349	-3.240884	2.641469
46	1	0	3.989059	-2.039672	3.456030
47	1	0	4.275510	0.339324	3.038795

Free Energy and Geometry for TS4:



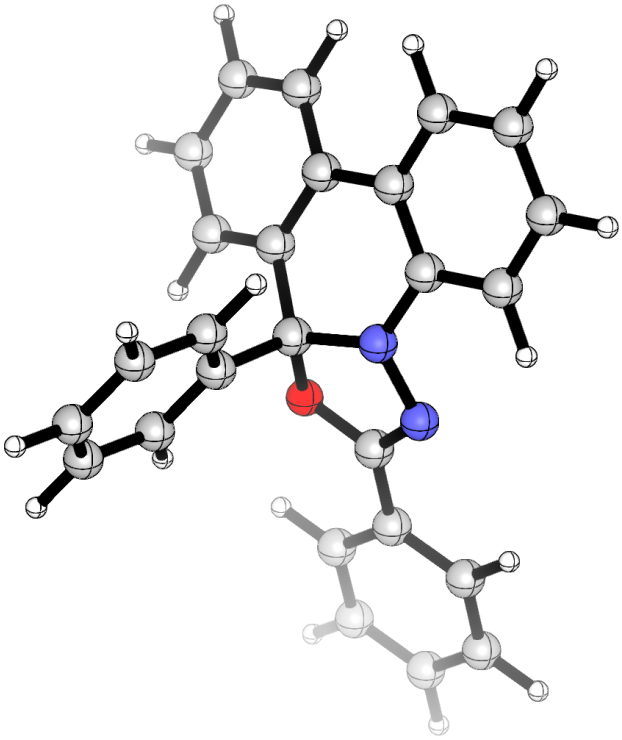
Sum of electronic and thermal free energies: -1185.642406 a.u.

Number of imaginary frequencies: 1

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	0.235452	3.607769	-2.122477
2	6	0	0.305207	2.238482	-2.364596
3	6	0	0.499418	1.424813	-1.262033
4	6	0	0.726956	1.918623	0.041566
5	6	0	0.404443	3.264711	0.311149
6	6	0	0.231824	4.081885	-0.794359
7	7	0	0.289649	0.522964	0.658002
8	6	0	0.241099	0.009449	-0.856357
9	8	0	-1.121319	-0.399502	-0.942578
10	6	0	-1.730199	-0.101852	0.221675
11	7	0	-1.013717	0.368708	1.177665
12	6	0	-3.164218	-0.384964	0.318959
13	6	0	-3.836751	-0.125704	1.516451
14	6	0	-5.192957	-0.398780	1.611443
15	6	0	-5.877477	-0.927221	0.517660
16	6	0	-5.205975	-1.182389	-0.673941
17	6	0	-3.846645	-0.911999	-0.778354
18	6	0	1.167520	-1.116201	-1.177619

19	6	0	0.765963	-2.442790	-1.015175
20	6	0	1.673153	-3.471245	-1.241356
21	6	0	2.981380	-3.177526	-1.617148
22	6	0	3.382497	-1.853904	-1.774366
23	6	0	2.476571	-0.822283	-1.557176
24	6	0	1.451452	0.196738	1.458155
25	6	0	1.665501	-0.936160	2.223898
26	6	0	2.938519	-1.041010	2.780042
27	6	0	3.901345	-0.057299	2.527118
28	6	0	3.620562	1.051869	1.722785
29	6	0	2.344612	1.203458	1.165926
30	1	0	0.102530	4.303952	-2.940217
31	1	0	0.149446	1.830481	-3.356944
32	1	0	0.398478	3.662887	1.317120
33	1	0	0.082677	5.143370	-0.626400
34	1	0	-3.292137	0.287249	2.356471
35	1	0	-5.718781	-0.198987	2.536776
36	1	0	-6.937415	-1.137738	0.595582
37	1	0	-5.740066	-1.589993	-1.523178
38	1	0	-3.316016	-1.103071	-1.702463
39	1	0	-0.252077	-2.669237	-0.721798
40	1	0	1.360088	-4.501373	-1.122012
41	1	0	3.687527	-3.981075	-1.789546
42	1	0	4.399936	-1.624285	-2.066283
43	1	0	2.779899	0.212763	-1.668987
44	1	0	0.903199	-1.690230	2.385242
45	1	0	3.186212	-1.890538	3.405065
46	1	0	4.886580	-0.164056	2.970204
47	1	0	4.403431	1.785370	1.551074

Free Energy and Geometry for 30:



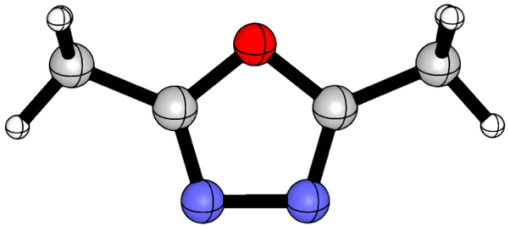
Sum of electronic and thermal free energies: -1185.826850 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-3.273126	0.908993	3.107662
2	6	0	-2.136136	1.716162	3.151295
3	6	0	-1.152035	1.553418	2.189582
4	6	0	-1.297356	0.591172	1.191988
5	6	0	-2.432664	-0.227343	1.130177
6	6	0	-3.415015	-0.049505	2.117690
7	6	0	-0.224232	0.473930	0.139376
8	7	0	-0.281492	-0.798670	-0.568849
9	6	0	-1.398825	-1.608056	-0.659532
10	6	0	-2.538599	-1.281296	0.100652
11	6	0	-1.402459	-2.713512	-1.519261
12	6	0	-2.559015	-3.458359	-1.671762
13	6	0	-3.721968	-3.108558	-0.982508
14	6	0	-3.700303	-2.034983	-0.106113
15	7	0	1.003013	-1.298633	-0.715282
16	6	0	1.737755	-0.570747	0.036088
17	8	0	1.080906	0.401770	0.732604

18	6	0	-0.261765	1.649515	-0.839222
19	6	0	0.675766	2.675557	-0.781007
20	6	0	0.587768	3.747983	-1.667245
21	6	0	-0.434876	3.796630	-2.607115
22	6	0	-1.373927	2.767799	-2.664147
23	6	0	-1.288162	1.697773	-1.783059
24	6	0	3.176641	-0.715514	0.249042
25	6	0	3.849574	0.169647	1.092448
26	6	0	5.217366	0.021794	1.298864
27	6	0	5.912972	-1.000528	0.662544
28	6	0	5.239315	-1.882043	-0.183135
29	6	0	3.875419	-1.743978	-0.391113
30	1	0	-4.047698	1.021936	3.856739
31	1	0	-2.023307	2.463909	3.926517
32	1	0	-0.262838	2.174344	2.201717
33	1	0	-4.292569	-0.682578	2.128114
34	1	0	-0.499162	-2.958035	-2.062609
35	1	0	-2.560304	-4.307307	-2.345165
36	1	0	-4.633687	-3.675278	-1.122614
37	1	0	-4.604052	-1.783545	0.434503
38	1	0	1.476300	2.634330	-0.052217
39	1	0	1.323554	4.542254	-1.623148
40	1	0	-0.500775	4.630050	-3.296327
41	1	0	-2.170742	2.799361	-3.397633
42	1	0	-2.016657	0.894169	-1.831133
43	1	0	3.301886	0.964529	1.583156
44	1	0	5.738488	0.707630	1.955630
45	1	0	6.978581	-1.112635	0.822836
46	1	0	5.780758	-2.678257	-0.679312
47	1	0	3.341648	-2.423625	-1.044107

Free Energy and Geometry for 2,5-dimethyl-1,3,4-oxadiazole (20):

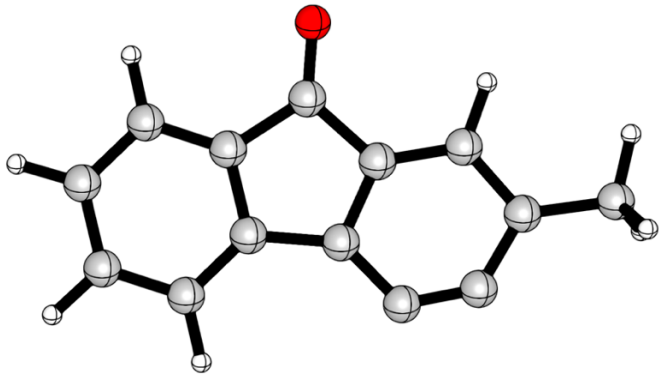


Sum of electronic and thermal free energies: -340.537358 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	7	0	-0.696533	1.247775	0.000023
2	6	0	-1.062519	0.011143	0.000044
3	8	0	0.000022	-0.831252	0.000028
4	6	0	1.062588	0.011278	0.000003
5	7	0	0.696462	1.247838	-0.000030
6	6	0	2.430627	-0.561113	-0.000012
7	1	0	3.153572	0.254225	0.000089
8	1	0	2.585480	-1.182374	0.885739
9	1	0	2.585538	-1.182195	-0.885880
10	6	0	-2.430628	-0.561103	-0.000026
11	1	0	-2.585764	-1.181789	-0.886145
12	1	0	-2.585474	-1.182728	0.885474
13	1	0	-3.153436	0.254362	0.000490

Free Energy and Geometry for G*:

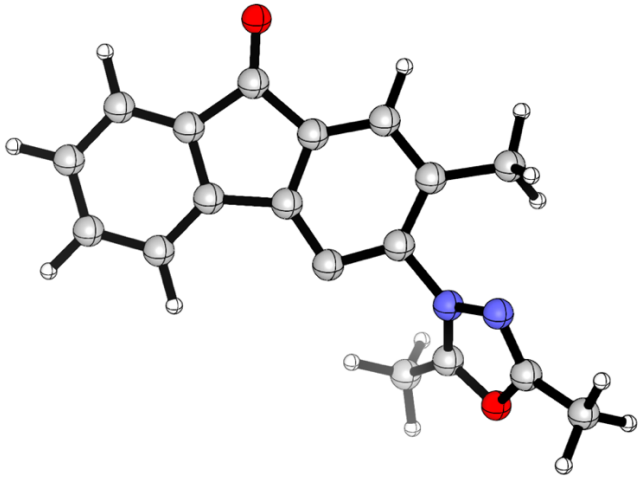


Sum of electronic and thermal free energies: -613.030307 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	2.151735	-1.690542	0.000022
2	6	0	1.175915	-0.708806	0.000046
3	6	0	1.531091	0.650059	0.000023
4	6	0	2.852432	1.054557	-0.000046
5	6	0	3.842584	0.064478	-0.000069
6	6	0	3.493060	-1.285023	-0.000033
7	6	0	-0.855711	0.509923	0.000035
8	6	0	-0.298258	-0.792984	0.000052
9	6	0	-1.289106	-1.754968	0.000031
10	6	0	-2.508286	-1.488017	-0.000004
11	6	0	-3.185337	-0.277963	-0.000039
12	6	0	-2.225901	0.766757	-0.000028
13	6	0	0.285007	1.487026	0.000128
14	8	0	0.218507	2.696441	-0.000002
15	6	0	-4.666511	-0.046855	-0.000051
16	1	0	1.887134	-2.744139	0.000033
17	1	0	3.105788	2.111289	-0.000058
18	1	0	4.890615	0.347936	-0.000110
19	1	0	4.275540	-2.038399	-0.000057
20	1	0	-2.573214	1.798436	-0.000052
21	1	0	-5.130342	-0.497668	-0.882365
22	1	0	-5.130232	-0.496906	0.882714
23	1	0	-4.889629	1.022067	-0.000488

Free Energy and Geometry for I (Conformer 1 of 2):



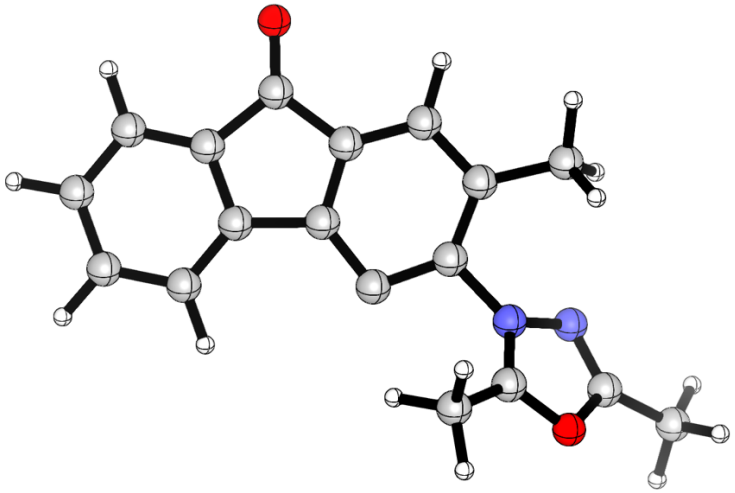
Sum of electronic and thermal free energies: -953.583090 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	2.835104	-2.085753	-0.312714
2	6	0	2.521730	-0.744098	-0.166014
3	6	0	3.548515	0.210463	-0.101482
4	6	0	4.884803	-0.139904	-0.178045
5	6	0	5.201058	-1.495135	-0.325230
6	6	0	4.185260	-2.450055	-0.391434
7	6	0	2.921823	1.562797	0.054854
8	6	0	1.445770	1.310373	0.074017
9	6	0	1.197913	-0.064809	-0.054937
10	6	0	-0.076766	-0.657122	-0.074865
11	6	0	-1.039292	0.349379	0.056492
12	6	0	-0.899404	1.743601	0.216933
13	6	0	0.412704	2.224016	0.217865
14	8	0	3.493969	2.630705	0.148317
15	6	0	-2.056251	2.694125	0.403656
16	7	0	-2.429060	-0.141726	0.039458
17	6	0	-2.902007	-1.166002	0.700418
18	8	0	-4.160896	-1.356706	0.312414
19	6	0	-4.412848	-0.391274	-0.617117
20	7	0	-3.386587	0.362257	-0.809429
21	6	0	-5.745676	-0.336687	-1.255351
22	6	0	-2.255253	-2.020654	1.713590
23	1	0	2.044203	-2.827919	-0.366059
24	1	0	5.659701	0.619782	-0.124589
25	1	0	6.238685	-1.806978	-0.389136
26	1	0	4.449227	-3.497494	-0.507121

27	1	0	0.614658	3.285098	0.340676
28	1	0	-1.694408	3.650375	0.789292
29	1	0	-2.580357	2.881757	-0.538033
30	1	0	-2.794678	2.301535	1.110856
31	1	0	-5.761051	0.489038	-1.965588
32	1	0	-5.948024	-1.274205	-1.778375
33	1	0	-6.518501	-0.184677	-0.498300
34	1	0	-2.114482	-1.448817	2.635675
35	1	0	-2.881628	-2.890169	1.909803
36	1	0	-1.271508	-2.292593	1.321033

Free Energy and Geometry for I (Conformer 2 of 2):



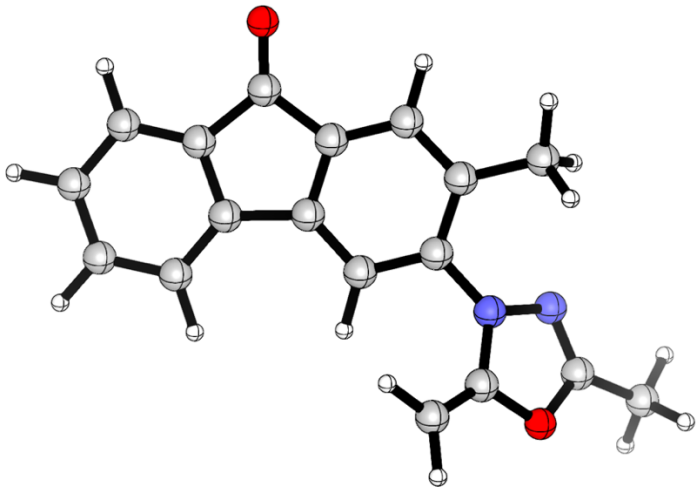
Sum of electronic and thermal free energies: -953.583066 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-2.835179	-2.085745	-0.312639
2	6	0	-2.521773	-0.744092	-0.166001
3	6	0	-3.548532	0.210502	-0.101545
4	6	0	-4.884829	-0.139830	-0.178119
5	6	0	-5.201119	-1.495062	-0.325231
6	6	0	-4.185345	-2.450014	-0.391371
7	6	0	-2.921806	1.562825	0.054773
8	6	0	-1.445763	1.310351	0.074023
9	6	0	-1.197938	-0.064827	-0.054941
10	6	0	0.076716	-0.657195	-0.074817
11	6	0	1.039278	0.349281	0.056593
12	6	0	0.899416	1.743503	0.217093
13	6	0	-0.412675	2.223958	0.217944
14	8	0	-3.493916	2.630750	0.148242
15	6	0	2.056256	2.694016	0.403899
16	7	0	2.429033	-0.141839	0.039418
17	6	0	2.902107	-1.166056	0.700384
18	8	0	4.161009	-1.356608	0.312358
19	6	0	4.412820	-0.391170	-0.617197
20	7	0	3.386483	0.362263	-0.809478
21	6	0	5.745598	-0.336462	-1.255524
22	6	0	2.255456	-2.020801	1.713546
23	1	0	-2.044296	-2.827933	-0.365938
24	1	0	-5.659706	0.619880	-0.124702
25	1	0	-6.238753	-1.806880	-0.389134
26	1	0	-4.449338	-3.497450	-0.507019

27	1	0	-0.614595	3.285045	0.340763
28	1	0	1.694392	3.650264	0.789519
29	1	0	2.794639	2.301429	1.111142
30	1	0	2.580434	2.881657	-0.537751
31	1	0	5.761010	0.489578	-1.965394
32	1	0	6.518501	-0.184897	-0.498466
33	1	0	5.947788	-1.273767	-1.778996
34	1	0	1.271221	-2.291754	1.321531
35	1	0	2.881308	-2.890927	1.908724
36	1	0	2.115922	-1.449446	2.636121

Free Energy and Geometry for J (Conformer 1 of 2):



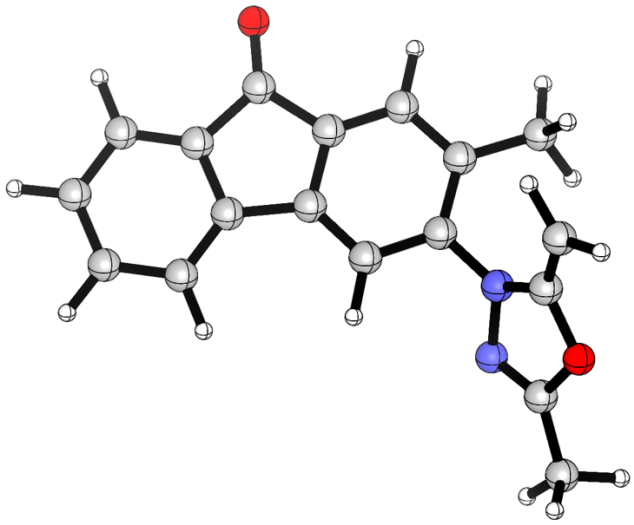
Sum of electronic and thermal free energies: -953.651364 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-2.821369	-2.104329	-0.244196
2	6	0	-2.512227	-0.758503	-0.130357
3	6	0	-3.536068	0.201797	-0.120294
4	6	0	-4.869473	-0.150034	-0.221397
5	6	0	-5.183123	-1.508401	-0.337317
6	6	0	-4.170411	-2.467005	-0.348145
7	6	0	-2.922818	1.563701	0.013362
8	6	0	-1.448735	1.322611	0.080147
9	6	0	-1.209919	-0.056078	-0.002227
10	6	0	0.085117	-0.535186	0.031583
11	6	0	1.136691	0.388003	0.160643
12	6	0	0.910711	1.774929	0.260757
13	6	0	-0.412653	2.228538	0.207116
14	8	0	-3.500555	2.628991	0.054994
15	6	0	2.041048	2.749418	0.455679
16	7	0	2.459890	-0.095202	0.191634
17	6	0	2.911589	-1.296646	0.734617
18	8	0	4.175639	-1.455215	0.212478
19	6	0	4.395291	-0.386313	-0.608934
20	7	0	3.420350	0.433914	-0.667927
21	6	0	2.363961	-2.152398	1.601708
22	6	0	5.695067	-0.311555	-1.315177
23	1	0	-2.045877	-2.864374	-0.253545
24	1	0	-5.642703	0.612384	-0.209849
25	1	0	-6.219096	-1.820426	-0.419218
26	1	0	-4.431749	-3.516744	-0.438879

27	1	0	0.309151	-1.593854	-0.052858
28	1	0	-0.624421	3.291851	0.286315
29	1	0	1.654399	3.701169	0.826914
30	1	0	2.770424	2.361169	1.172863
31	1	0	2.579127	2.931514	-0.478339
32	1	0	2.927219	-3.020608	1.912083
33	1	0	1.382427	-1.970998	2.014274
34	1	0	6.514455	-0.270202	-0.592773
35	1	0	5.833978	-1.198489	-1.938632
36	1	0	5.714242	0.581110	-1.939487

Free Energy and Geometry for J (Conformer 2 of 2):



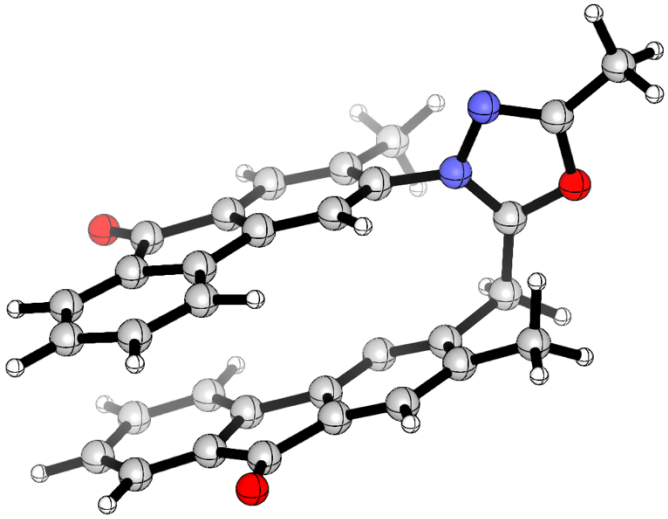
Sum of electronic and thermal free energies: -953.651457 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-2.715451	-2.210908	0.206364
2	6	0	-2.463346	-0.855713	0.064823
3	6	0	-3.527826	0.057847	0.011174
4	6	0	-4.846581	-0.350328	0.096017
5	6	0	-5.102415	-1.717740	0.240162
6	6	0	-4.048854	-2.630200	0.293877
7	6	0	-2.972970	1.441349	-0.146001
8	6	0	-1.486949	1.264964	-0.177992
9	6	0	-1.189841	-0.101464	-0.054513
10	6	0	0.125191	-0.520161	-0.047996
11	6	0	1.133644	0.449984	-0.176395
12	6	0	0.850363	1.817247	-0.346836
13	6	0	-0.495227	2.213522	-0.325635
14	8	0	-3.594339	2.478988	-0.228580
15	6	0	1.937455	2.821879	-0.618532
16	7	0	2.477761	0.023256	-0.161576
17	6	0	3.412653	0.317571	0.831181
18	8	0	4.450166	-0.556189	0.590424
19	6	0	4.002637	-1.427532	-0.362145
20	7	0	2.838353	-1.156734	-0.809854
21	6	0	3.391479	1.183591	1.846024
22	6	0	4.900768	-2.534727	-0.763464
23	1	0	-1.907456	-2.935052	0.248872
24	1	0	-5.652107	0.376568	0.050868
25	1	0	-6.125043	-2.073498	0.310389

26	1	0	-4.265971	-3.687937	0.405710
27	1	0	0.406171	-1.563281	0.056264
28	1	0	-0.755741	3.260861	-0.455842
29	1	0	1.523469	3.689962	-1.136229
30	1	0	2.419320	3.172335	0.299606
31	1	0	2.720578	2.380414	-1.241711
32	1	0	4.239909	1.242169	2.512368
33	1	0	2.523956	1.803016	2.021524
34	1	0	5.830819	-2.132536	-1.173987
35	1	0	5.149466	-3.151041	0.104191
36	1	0	4.404832	-3.145097	-1.517449

Free Energy and Geometry for K (Conformer 1 of 4):



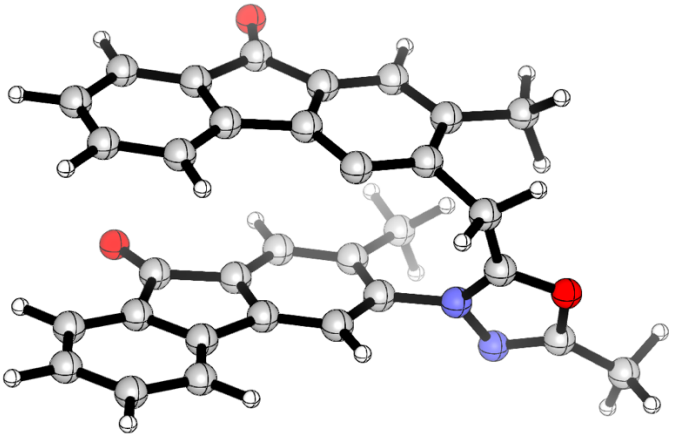
Sum of electronic and thermal free energies: -1566.715148 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	1.869924	0.615816	2.435735
2	6	0	1.607929	-0.501608	1.661399
3	6	0	2.655185	-1.349649	1.263458
4	6	0	3.965055	-1.115791	1.637302
5	6	0	4.230802	0.010328	2.423830
6	6	0	3.197559	0.863776	2.807644
7	6	0	2.103965	-2.427957	0.390052
8	6	0	0.633515	-2.128395	0.283146
9	6	0	0.345006	-1.002483	1.069832
10	6	0	-0.951014	-0.529102	1.134839
11	6	0	-1.900447	-1.188070	0.351689
12	6	0	-1.642510	-2.298595	-0.451115
13	6	0	-0.326439	-2.782616	-0.456772
14	8	0	2.694385	-3.354739	-0.119172
15	6	0	-2.698201	-2.922082	-1.322556
16	7	0	-3.230060	-0.627391	0.314876
17	6	0	-3.733183	0.179958	-0.594002
18	8	0	-4.989156	0.424026	-0.240599
19	6	0	-5.208624	-0.268786	0.917692
20	7	0	-4.161405	-0.922814	1.284609
21	6	0	-6.534825	-0.185089	1.564004
22	6	0	-3.082880	0.794988	-1.774995
23	6	0	-1.688218	1.318834	-1.405484
24	6	0	-1.642466	2.407776	-0.501931
25	6	0	-0.391026	2.850557	-0.061510
26	6	0	0.726926	2.169712	-0.514029

27	6	0	0.609241	1.082221	-1.399011
28	6	0	-0.594456	0.580780	-1.930388
29	6	0	-2.889700	3.078143	0.029007
30	6	0	1.986718	0.543072	-1.597564
31	6	0	2.914767	1.331553	-0.894935
32	6	0	2.162441	2.412443	-0.181532
33	6	0	4.265850	1.042167	-0.879975
34	6	0	4.704746	-0.089429	-1.579891
35	6	0	3.789082	-0.888554	-2.264181
36	6	0	2.421575	-0.579344	-2.284520
37	8	0	2.628512	3.289633	0.522563
38	1	0	1.079346	1.302164	2.725224
39	1	0	4.758040	-1.779744	1.306561
40	1	0	5.249242	0.231991	2.726045
41	1	0	3.425529	1.745587	3.397916
42	1	0	-1.225890	0.356911	1.698999
43	1	0	-0.061934	-3.645270	-1.062243
44	1	0	-2.445658	-3.962129	-1.537947
45	1	0	-3.688078	-2.901937	-0.858379
46	1	0	-2.753276	-2.392303	-2.280812
47	1	0	-6.524838	-0.792355	2.468107
48	1	0	-6.758776	0.853286	1.819089
49	1	0	-7.305227	-0.551839	0.881906
50	1	0	-2.936190	0.016037	-2.530951
51	1	0	-3.780445	1.543586	-2.164563
52	1	0	-0.299307	3.691462	0.622965
53	1	0	-2.637957	4.007581	0.546772
54	1	0	-3.604717	3.323474	-0.764243
55	1	0	-3.420779	2.448051	0.758140
56	1	0	4.957622	1.667613	-0.322015
57	1	0	5.757885	-0.353410	-1.582164
58	1	0	4.142879	-1.772616	-2.787340
59	1	0	1.705065	-1.203502	-2.811221

Free Energy and Geometry for K (Conformer 2 of 4):



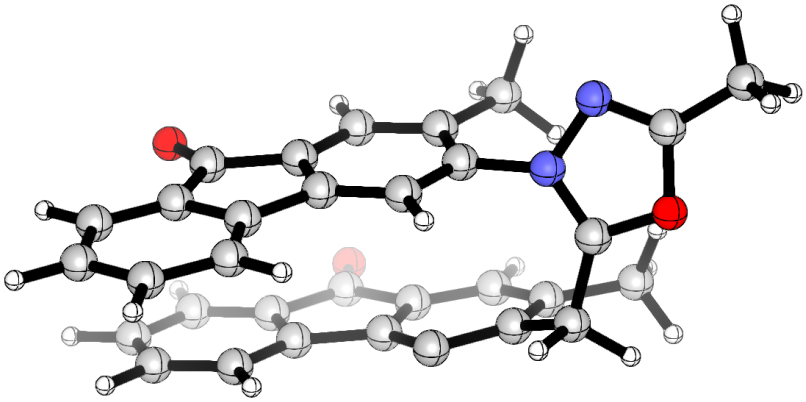
Sum of electronic and thermal free energies: -1566.711379 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	2.122597	-3.407269	-0.965126
2	6	0	1.933757	-2.398260	-0.033858
3	6	0	3.032822	-1.845674	0.640075
4	6	0	4.325208	-2.279959	0.410913
5	6	0	4.517705	-3.300274	-0.525859
6	6	0	3.429154	-3.850914	-1.203027
7	6	0	2.549952	-0.750811	1.540421
8	6	0	1.056870	-0.726728	1.359988
9	6	0	0.705923	-1.702924	0.420083
10	6	0	-0.618248	-1.846971	0.047052
11	6	0	-1.545325	-1.008457	0.663963
12	6	0	-1.231315	-0.042581	1.625175
13	6	0	0.122250	0.094468	1.960176
14	8	0	3.209713	-0.041505	2.265462
15	6	0	-2.286887	0.811879	2.271070
16	7	0	-2.919569	-1.116799	0.236323
17	6	0	-3.440836	-0.771080	-0.922827
18	8	0	-4.733106	-1.071636	-0.868822
19	6	0	-4.960675	-1.594350	0.373519
20	7	0	-3.881165	-1.637810	1.073528
21	6	0	-6.329807	-2.016144	0.735449
22	6	0	-2.817158	-0.108715	-2.096938
23	6	0	-1.807437	0.943039	-1.630753
24	6	0	-2.332247	2.064347	-0.945906
25	6	0	-1.436381	2.928247	-0.307214
26	6	0	-0.087650	2.624807	-0.385319
27	6	0	0.371500	1.532712	-1.145649
28	6	0	-0.439974	0.615442	-1.834851

29	6	0	-3.817914	2.336416	-0.863223
30	6	0	1.855200	1.491006	-0.988579
31	6	0	2.272305	2.523901	-0.131644
32	6	0	1.061016	3.302939	0.283624
33	6	0	3.598008	2.699860	0.219392
34	6	0	4.543491	1.813042	-0.311084
35	6	0	4.139339	0.788884	-1.166868
36	6	0	2.791642	0.611834	-1.509386
37	8	0	1.031397	4.273091	1.018926
38	1	0	1.287486	-3.842415	-1.505589
39	1	0	5.159200	-1.825412	0.937656
40	1	0	5.518609	-3.664481	-0.733239
41	1	0	3.597911	-4.638071	-1.931253
42	1	0	-0.937439	-2.563403	-0.702967
43	1	0	0.433327	0.851382	2.675547
44	1	0	-2.826965	0.249411	3.040295
45	1	0	-1.826666	1.684365	2.738866
46	1	0	-3.015899	1.170846	1.539292
47	1	0	-6.319113	-2.416167	1.748432
48	1	0	-7.007856	-1.161106	0.683517
49	1	0	-6.679040	-2.782230	0.039502
50	1	0	-2.259294	-0.863930	-2.661874
51	1	0	-3.641603	0.261839	-2.715964
52	1	0	-1.789034	3.790600	0.254881
53	1	0	-4.009313	3.292856	-0.369153
54	1	0	-4.282816	2.373896	-1.855184
55	1	0	-4.361954	1.571189	-0.289197
56	1	0	3.890335	3.501942	0.891680
57	1	0	5.592768	1.919869	-0.054407
58	1	0	4.882547	0.102741	-1.564406
59	1	0	2.474628	-0.201347	-2.156651

Free Energy and Geometry for K (Conformer 3 of 4):



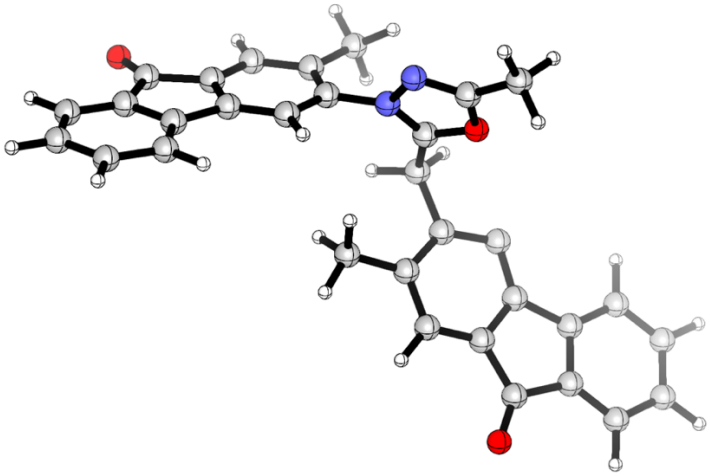
Sum of electronic and thermal free energies: -1566.711392 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-2.122687	-3.407310	-0.964919
2	6	0	-1.933873	-2.398141	-0.033813
3	6	0	-3.032952	-1.845482	0.640039
4	6	0	-4.325329	-2.279873	0.410976
5	6	0	-4.517794	-3.300356	-0.525619
6	6	0	-3.429228	-3.851056	-1.202725
7	6	0	-2.550098	-0.750561	1.540341
8	6	0	-1.057021	-0.726503	1.359927
9	6	0	-0.706053	-1.702772	0.420114
10	6	0	0.618134	-1.846881	0.047123
11	6	0	1.545243	-1.008370	0.664003
12	6	0	1.231187	-0.042409	1.625130
13	6	0	-0.122381	0.094717	1.960067
14	8	0	-3.209867	-0.041161	2.265285
15	6	0	2.286725	0.812061	2.271078
16	7	0	2.919478	-1.116779	0.236468
17	6	0	3.440681	-0.771432	-0.922835
18	8	0	4.732957	-1.071959	-0.868791
19	6	0	4.960589	-1.594250	0.373713
20	7	0	3.881099	-1.637495	1.073783
21	6	0	6.329752	-2.015902	0.735710
22	6	0	2.816987	-0.109254	-2.097039
23	6	0	1.807462	0.942718	-1.630960
24	6	0	2.332402	2.063950	-0.946091
25	6	0	1.436659	2.927959	-0.307355
26	6	0	0.087884	2.624717	-0.385472
27	6	0	-0.371408	1.532716	-1.145871

28	6	0	0.439940	0.615357	-1.835080
29	6	0	3.818109	2.335780	-0.863321
30	6	0	-1.855085	1.491120	-0.988721
31	6	0	-2.272073	2.523992	-0.131708
32	6	0	-1.060705	3.302928	0.283526
33	6	0	-3.597750	2.699984	0.219424
34	6	0	-4.543308	1.813228	-0.311035
35	6	0	-4.139263	0.789085	-1.166892
36	6	0	-2.791595	0.612004	-1.509514
37	8	0	-1.030959	4.272984	1.018954
38	1	0	-1.287563	-3.842522	-1.505309
39	1	0	-5.159325	-1.825323	0.937709
40	1	0	-5.518682	-3.664655	-0.732909
41	1	0	-3.597965	-4.638342	-1.930814
42	1	0	0.937281	-2.563428	-0.702808
43	1	0	-0.433454	0.851711	2.675359
44	1	0	1.826640	1.685353	2.737514
45	1	0	2.825658	0.250034	3.041431
46	1	0	3.016721	1.169750	1.539668
47	1	0	6.319162	-2.415481	1.748869
48	1	0	6.678906	-2.782309	0.040073
49	1	0	7.007810	-1.160901	0.683318
50	1	0	3.641437	0.261024	-2.716228
51	1	0	2.258942	-0.864484	-2.661787
52	1	0	1.789454	3.790222	0.254792
53	1	0	4.009600	3.292588	-0.370005
54	1	0	4.361845	1.570922	-0.288514
55	1	0	4.283240	2.372318	-1.855210
56	1	0	-3.889998	3.502020	0.891799
57	1	0	-5.592562	1.920089	-0.054281
58	1	0	-4.882533	0.103008	-1.564419
59	1	0	-2.474616	-0.201169	-2.156803

Free Energy and Geometry for K (Conformer 4 of 4):



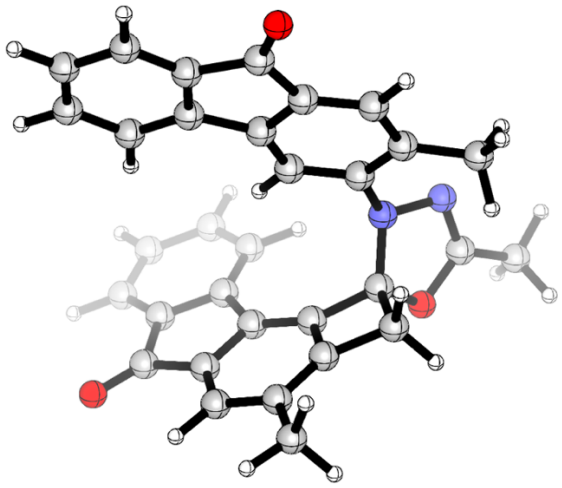
Sum of electronic and thermal free energies: -1566.705033 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-5.096280	-1.906963	1.662961
2	6	0	-5.057746	-1.080934	0.551353
3	6	0	-6.075682	-1.141878	-0.413138
4	6	0	-7.142812	-2.014862	-0.293328
5	6	0	-7.183840	-2.848455	0.828080
6	6	0	-6.173481	-2.792015	1.788692
7	6	0	-5.782143	-0.153616	-1.495647
8	6	0	-4.489060	0.502173	-1.087240
9	6	0	-4.071824	-0.055428	0.131561
10	6	0	-2.902806	0.389123	0.716471
11	6	0	-2.185478	1.383821	0.040896
12	6	0	-2.591004	1.978605	-1.158001
13	6	0	-3.783228	1.497246	-1.726954
14	8	0	-6.430984	0.082141	-2.488764
15	6	0	-1.828178	3.097141	-1.818319
16	7	0	-0.969832	1.827445	0.665745
17	6	0	0.260122	1.765746	0.196948
18	8	0	1.047933	2.305749	1.115165
19	6	0	0.243713	2.669356	2.154776
20	7	0	-0.993496	2.392783	1.923373
21	6	0	0.852676	3.298745	3.344511
22	6	0	0.794985	1.169611	-1.041525
23	6	0	1.925837	0.180773	-0.698094
24	6	0	1.539164	-1.114320	-0.281999
25	6	0	2.547653	-2.038957	0.010114
26	6	0	3.861677	-1.617410	-0.105403
27	6	0	4.171555	-0.301664	-0.492880

28	6	0	3.239349	0.699261	-0.819847
29	6	0	0.092462	-1.522180	-0.127776
30	6	0	5.660589	-0.189509	-0.493594
31	6	0	6.230262	-1.416131	-0.116785
32	6	0	5.116546	-2.384724	0.151224
33	6	0	7.599193	-1.599464	-0.035436
34	6	0	8.427684	-0.513657	-0.341270
35	6	0	7.869532	0.709951	-0.715511
36	6	0	6.482369	0.885350	-0.796343
37	8	0	5.227029	-3.542866	0.508861
38	1	0	-4.317344	-1.877794	2.418568
39	1	0	-7.918561	-2.044566	-1.052297
40	1	0	-8.005265	-3.545716	0.954171
41	1	0	-6.222196	-3.448446	2.651596
42	1	0	-2.533505	0.001106	1.660836
43	1	0	-4.150660	1.920102	-2.657852
44	1	0	-2.509507	3.702209	-2.419347
45	1	0	-1.349547	3.755147	-1.087530
46	1	0	-1.052307	2.714664	-2.490086
47	1	0	0.069996	3.517075	4.069659
48	1	0	1.588690	2.621802	3.784190
49	1	0	1.358919	4.222687	3.055692
50	1	0	-0.042824	0.735108	-1.595111
51	1	0	1.249337	1.976013	-1.625077
52	1	0	2.307142	-3.052946	0.321815
53	1	0	0.013772	-2.581638	0.130127
54	1	0	-0.405078	-0.960677	0.674516
55	1	0	-0.492249	-1.360965	-1.041626
56	1	0	8.011555	-2.561350	0.257138
57	1	0	9.506591	-0.620886	-0.288652
58	1	0	8.527345	1.542597	-0.949431
59	1	0	6.046337	1.836264	-1.088221

Free Energy and Geometry for L (Conformer 1 of 2):



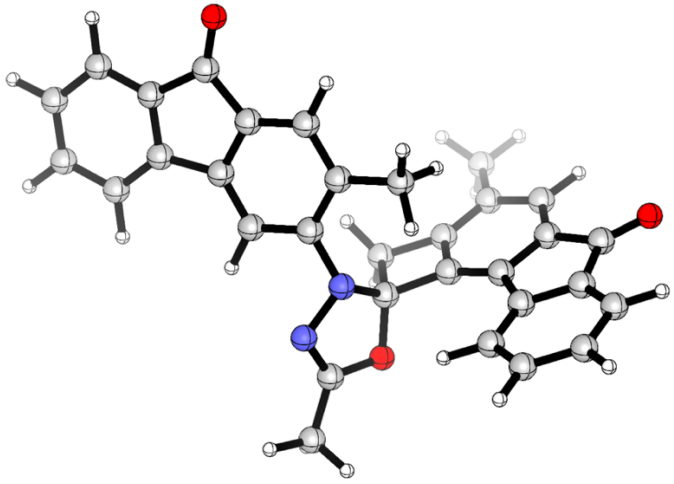
Sum of electronic and thermal free energies: -1566.784716 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	2.585746	2.475185	-0.579955
2	6	0	3.083318	1.190838	-0.429272
3	6	0	4.455680	0.984404	-0.217818
4	6	0	5.351036	2.036518	-0.155383
5	6	0	4.851180	3.333840	-0.310571
6	6	0	3.488221	3.544581	-0.518816
7	6	0	4.709412	-0.487697	-0.082232
8	6	0	3.366658	-1.130631	-0.233764
9	6	0	2.407041	-0.130127	-0.438584
10	6	0	1.085418	-0.480273	-0.629432
11	6	0	0.724167	-1.838755	-0.581169
12	6	0	1.677842	-2.850282	-0.346489
13	6	0	3.018258	-2.466926	-0.192418
14	6	0	1.304598	-4.305876	-0.223350
15	8	0	5.773799	-1.035719	0.109924
16	7	0	-0.655567	-2.102821	-0.757917
17	6	0	-1.589233	-1.886747	0.344439
18	8	0	-2.727658	-2.595407	-0.123012
19	6	0	-2.261028	-3.460605	-1.075848
20	7	0	-1.059560	-3.257483	-1.445248
21	6	0	-1.172362	-2.246803	1.833233
22	6	0	-1.479635	-0.791750	2.145332
23	6	0	-1.832665	-0.480268	0.834727
24	6	0	-3.205546	-4.480975	-1.590891
25	6	0	-1.462364	0.133199	3.186230
26	6	0	-1.828948	1.441802	2.819888
27	6	0	-2.161940	1.750275	1.505344

28	6	0	-2.169302	0.804997	0.463897
29	6	0	-1.072260	-0.235953	4.590467
30	6	0	-2.514519	1.472908	-0.808096
31	6	0	-2.735117	2.833811	-0.543350
32	6	0	-2.532344	3.083044	0.924000
33	6	0	-3.069104	3.721296	-1.549224
34	6	0	-3.178910	3.223781	-2.853394
35	6	0	-2.953737	1.873330	-3.119372
36	6	0	-2.617211	0.976179	-2.097171
37	8	0	-2.637699	4.138667	1.509196
38	1	0	1.526639	2.656361	-0.739228
39	1	0	6.408319	1.851375	0.009722
40	1	0	5.525312	4.182990	-0.268054
41	1	0	3.118004	4.558415	-0.635177
42	1	0	0.316717	0.257248	-0.841327
43	1	0	3.779814	-3.222339	-0.014898
44	1	0	2.135991	-4.865565	0.211563
45	1	0	0.426564	-4.441239	0.415730
46	1	0	1.058779	-4.742134	-1.194684
47	1	0	-1.823098	-2.991680	2.299553
48	1	0	-0.122679	-2.537236	1.950249
49	1	0	-2.709146	-5.085780	-2.349201
50	1	0	-3.551427	-5.121887	-0.775705
51	1	0	-4.079799	-3.991838	-2.029871
52	1	0	-1.840346	2.232788	3.566452
53	1	0	-1.075632	0.639005	5.244333
54	1	0	-1.764021	-0.976210	5.005380
55	1	0	-0.070958	-0.677932	4.612438
56	1	0	-3.237043	4.770885	-1.327006
57	1	0	-3.438594	3.893654	-3.666484
58	1	0	-3.040168	1.509842	-4.138494
59	1	0	-2.438966	-0.074849	-2.307747

Free Energy and Geometry for L (Conformer 2 of 2):



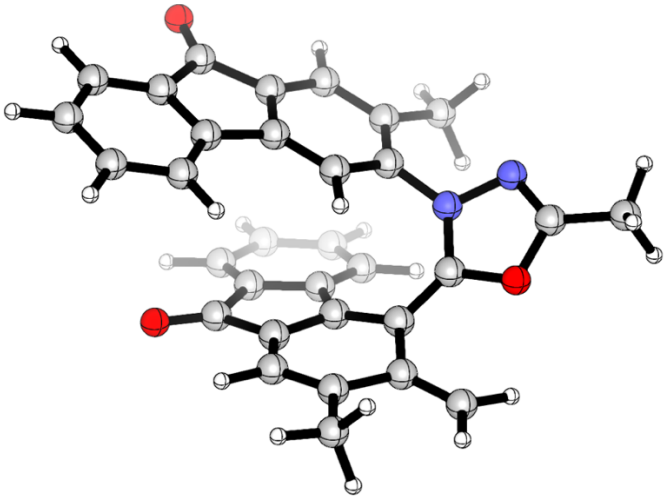
Sum of electronic and thermal free energies: -1566.785821 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-5.649502	1.237375	0.435496
2	6	0	-4.902223	0.239475	-0.169567
3	6	0	-5.537558	-0.898770	-0.690787
4	6	0	-6.908644	-1.066594	-0.622631
5	6	0	-7.663869	-0.060308	-0.011591
6	6	0	-7.038453	1.072871	0.508098
7	6	0	-4.500416	-1.804715	-1.284179
8	6	0	-3.198150	-1.101570	-1.066166
9	6	0	-3.441635	0.111865	-0.405574
10	6	0	-2.388336	0.945358	-0.089248
11	6	0	-1.082515	0.558164	-0.447212
12	6	0	-0.832232	-0.643353	-1.135291
13	6	0	-1.922059	-1.477272	-1.431485
14	6	0	0.543113	-1.039118	-1.604929
15	8	0	-4.681235	-2.876122	-1.822286
16	7	0	0.008579	1.411164	-0.110765
17	6	0	0.799323	1.092854	1.097458
18	8	0	1.210081	2.385561	1.523885
19	6	0	0.404492	3.275356	0.878959
20	7	0	-0.335322	2.779807	-0.028819
21	6	0	0.179976	0.196505	2.248536
22	6	0	1.367344	-0.722176	2.008909
23	6	0	1.917354	0.082954	1.015870
24	6	0	0.514444	4.701355	1.272686
25	6	0	1.927700	-1.925255	2.432374
26	6	0	3.124545	-2.280198	1.781974

27	6	0	3.674917	-1.463590	0.799195
28	6	0	3.092683	-0.254870	0.379369
29	6	0	1.304543	-2.775580	3.504362
30	6	0	3.904230	0.335268	-0.703948
31	6	0	5.000484	-0.508261	-0.941519
32	6	0	4.919989	-1.683611	-0.009802
33	6	0	5.940136	-0.216636	-1.912631
34	6	0	5.766849	0.952369	-2.663317
35	6	0	4.675005	1.789102	-2.432487
36	6	0	3.725875	1.491100	-1.446230
37	8	0	5.692931	-2.613411	0.066383
38	1	0	-5.179038	2.126650	0.844156
39	1	0	-7.375702	-1.956077	-1.034942
40	1	0	-8.742082	-0.158885	0.059150
41	1	0	-7.640130	1.844443	0.978429
42	1	0	-2.534560	1.891097	0.421815
43	1	0	-1.760370	-2.408166	-1.969592
44	1	0	1.038076	-1.707988	-0.892150
45	1	0	0.470695	-1.568546	-2.558757
46	1	0	1.180592	-0.160896	-1.736494
47	1	0	0.167382	0.706832	3.215679
48	1	0	-0.807333	-0.222559	2.035104
49	1	0	-0.181348	5.296983	0.682769
50	1	0	0.290685	4.815112	2.336430
51	1	0	1.534573	5.056728	1.102457
52	1	0	3.631878	-3.206221	2.043326
53	1	0	1.835968	-3.723331	3.615799
54	1	0	1.322481	-2.258961	4.469749
55	1	0	0.257459	-2.992347	3.270857
56	1	0	6.782091	-0.880670	-2.083877
57	1	0	6.485522	1.210124	-3.434256
58	1	0	4.557828	2.688259	-3.029142
59	1	0	2.873850	2.142832	-1.271458

Free Energy and Geometry for M (Conformer 1 of 2):



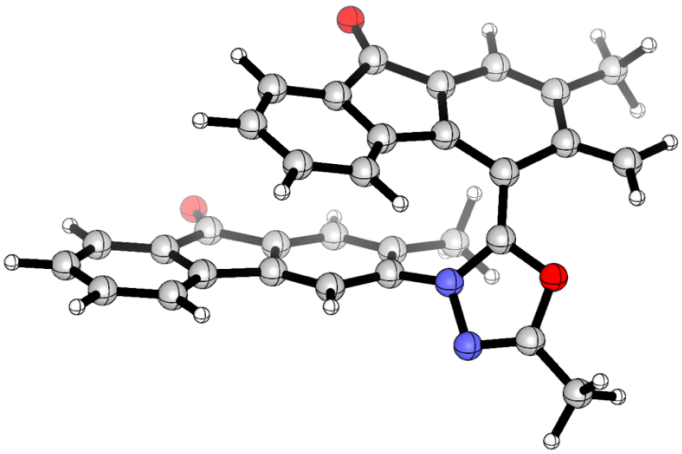
Sum of electronic and thermal free energies: -1566.769334 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	2.711186	-0.193023	-0.269550
2	6	0	2.284246	0.914994	0.433334
3	6	0	1.049379	0.884554	1.163088
4	6	0	0.258568	1.998824	1.221061
5	6	0	0.663977	3.237217	0.619054
6	6	0	1.923931	3.384227	0.140624
7	6	0	2.887833	2.254419	0.176152
8	6	0	4.197248	2.454066	-0.075919
9	6	0	2.397061	4.710816	-0.383920
10	6	0	-1.006197	1.667240	1.917382
11	6	0	-0.849096	0.237441	2.365169
12	6	0	0.414013	-0.210352	1.947789
13	6	0	0.875157	-1.453340	2.339520
14	6	0	0.022329	-2.269797	3.100259
15	6	0	-1.246421	-1.837843	3.471097
16	6	0	-1.691838	-0.554548	3.114333
17	8	0	-1.975934	2.380045	2.086802
18	7	0	2.049848	-1.336039	-0.646446
19	7	0	2.896341	-2.156597	-1.383278
20	6	0	3.994640	-1.507031	-1.455184
21	8	0	3.953113	-0.303530	-0.809338
22	6	0	5.253212	-1.893390	-2.130967
23	6	0	0.640091	-1.499130	-0.792614
24	6	0	0.063848	-2.743177	-0.495129
25	6	0	-1.332853	-2.842883	-0.558719
26	6	0	-2.085771	-1.729427	-0.876649

27	6	0	-1.487781	-0.499099	-1.180455
28	6	0	-0.113152	-0.380768	-1.178883
29	6	0	0.894375	-3.925267	-0.076448
30	6	0	-2.549972	0.507766	-1.413684
31	6	0	-3.796296	-0.122758	-1.275364
32	6	0	-3.574592	-1.566407	-0.938249
33	6	0	-4.983558	0.572942	-1.413779
34	6	0	-4.912467	1.941304	-1.695157
35	6	0	-3.675834	2.574144	-1.821238
36	6	0	-2.476194	1.865309	-1.680296
37	8	0	-4.415618	-2.418403	-0.749808
38	1	0	-0.033585	4.071003	0.609960
39	1	0	4.570741	3.432421	-0.354034
40	1	0	4.925099	1.657534	0.000301
41	1	0	2.818450	4.614396	-1.390884
42	1	0	1.572761	5.426539	-0.417418
43	1	0	3.184080	5.129254	0.254129
44	1	0	1.869402	-1.797128	2.067644
45	1	0	0.363292	-3.255359	3.403196
46	1	0	-1.888359	-2.489852	4.054495
47	1	0	-2.665692	-0.186668	3.423597
48	1	0	5.117720	-2.861415	-2.611848
49	1	0	5.515576	-1.143316	-2.881136
50	1	0	6.067883	-1.954509	-1.405220
51	1	0	-1.820445	-3.783794	-0.317865
52	1	0	0.382051	0.555343	-1.417615
53	1	0	0.267154	-4.665192	0.425683
54	1	0	1.371350	-4.399794	-0.939174
55	1	0	1.695185	-3.625342	0.606022
56	1	0	-5.936905	0.065838	-1.298899
57	1	0	-5.824141	2.518708	-1.807816
58	1	0	-3.641887	3.639160	-2.028170
59	1	0	-1.519990	2.373580	-1.768055

Free Energy and Geometry for M (Conformer 2 of 2):



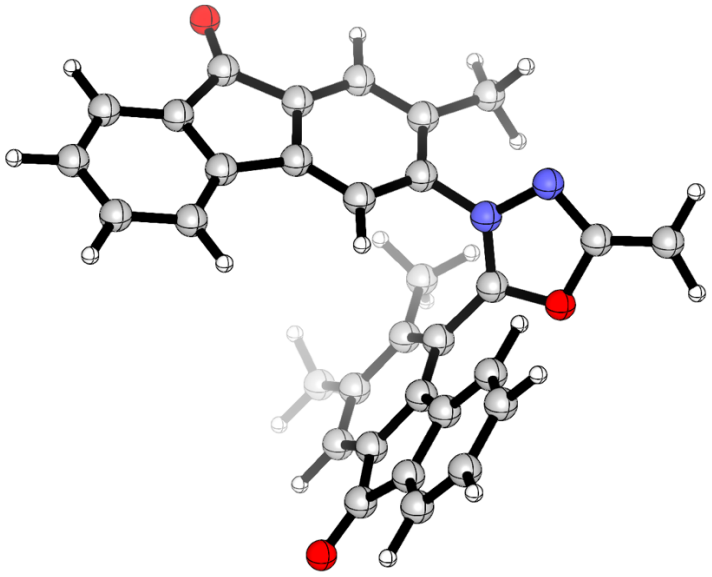
Sum of electronic and thermal free energies: -1566.767404 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	2.448592	1.297568	-0.263580
2	6	0	2.728523	-0.024616	-0.560609
3	6	0	1.653481	-0.938601	-0.793106
4	6	0	1.752185	-2.245610	-0.396189
5	6	0	2.960900	-2.753632	0.186525
6	6	0	4.084428	-1.993605	0.210880
7	6	0	4.079042	-0.599200	-0.302462
8	6	0	5.230740	0.089260	-0.447643
9	6	0	5.380383	-2.558594	0.720798
10	6	0	0.457674	-2.921998	-0.622200
11	6	0	-0.408520	-1.902033	-1.319483
12	6	0	0.353041	-0.736789	-1.490948
13	6	0	-0.122847	0.295862	-2.278385
14	6	0	-1.416568	0.181854	-2.811548
15	6	0	-2.197541	-0.944474	-2.573162
16	6	0	-1.682374	-2.021068	-1.833347
17	8	0	0.136777	-4.053830	-0.313560
18	7	0	1.296795	1.885468	0.172933
19	7	0	1.472352	3.251885	0.321762
20	6	0	2.709611	3.443753	0.053722
21	8	0	3.368147	2.295906	-0.289209
22	6	0	3.475428	4.709643	0.076851
23	6	0	0.151599	1.254528	0.745796
24	6	0	0.316500	0.309020	1.768931
25	6	0	-0.827781	-0.394181	2.183434
26	6	0	-2.047205	-0.119590	1.602452
27	6	0	-2.199536	0.883505	0.631706
28	6	0	-1.097425	1.595233	0.209522

29	6	0	1.640207	0.043584	2.434482
30	6	0	-3.615035	0.913072	0.192461
31	6	0	-4.321933	-0.068546	0.904069
32	6	0	-3.381094	-0.762835	1.840600
33	6	0	-5.670583	-0.294647	0.692969
34	6	0	-6.325305	0.487794	-0.262971
35	6	0	-5.626448	1.463169	-0.975496
36	6	0	-4.261978	1.687998	-0.757343
37	8	0	-3.638181	-1.653556	2.620300
38	1	0	2.978602	-3.775697	0.556356
39	1	0	6.180260	-0.341547	-0.153797
40	1	0	5.257183	1.084560	-0.870121
41	1	0	5.805820	-1.929452	1.511006
42	1	0	5.230610	-3.564290	1.119515
43	1	0	6.127675	-2.616830	-0.079166
44	1	0	0.474372	1.184868	-2.465165
45	1	0	-1.816764	0.991992	-3.414326
46	1	0	-3.202781	-0.998332	-2.979103
47	1	0	-2.257790	-2.929213	-1.679564
48	1	0	2.814687	5.520804	0.380421
49	1	0	4.304615	4.627495	0.784056
50	1	0	3.886460	4.920782	-0.913314
51	1	0	-0.747766	-1.150677	2.959792
52	1	0	-1.154324	2.353606	-0.564801
53	1	0	1.473219	-0.240783	3.476201
54	1	0	2.182684	-0.772727	1.944491
55	1	0	2.284245	0.927698	2.422638
56	1	0	-6.195253	-1.061216	1.255404
57	1	0	-7.382298	0.336509	-0.455483
58	1	0	-6.151030	2.059355	-1.715699
59	1	0	-3.731380	2.448518	-1.322807

Free Energy and Geometry for N (Conformer 1 of 4):



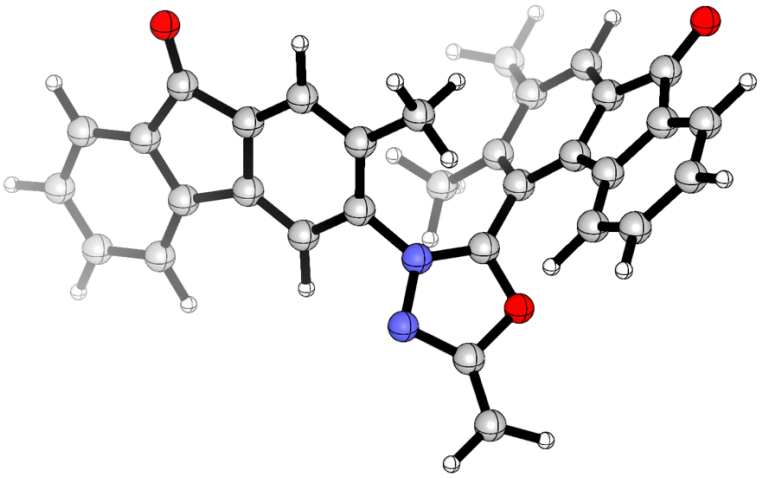
Sum of electronic and thermal free energies: -1566.767890 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-2.446653	2.581086	-1.226925
2	6	0	-3.045705	1.384708	-0.867604
3	6	0	-4.432638	1.321504	-0.660703
4	6	0	-5.243746	2.432699	-0.805686
5	6	0	-4.641101	3.641004	-1.169388
6	6	0	-3.263122	3.709026	-1.375477
7	6	0	-4.804414	-0.077957	-0.281762
8	6	0	-3.509704	-0.841373	-0.284412
9	6	0	-2.473776	0.036102	-0.631538
10	6	0	-1.176882	-0.436780	-0.705560
11	6	0	-0.960845	-1.788286	-0.414381
12	6	0	-1.978401	-2.686963	-0.067217
13	6	0	-3.283585	-2.174827	-0.008498
14	8	0	-5.905468	-0.510555	-0.025015
15	6	0	-1.710163	-4.133452	0.249645
16	7	0	0.390624	-2.260970	-0.462813
17	6	0	1.404904	-1.740161	0.179160
18	8	0	2.495498	-2.438605	-0.136796
19	6	0	2.077201	-3.449541	-1.044785
20	7	0	0.728115	-3.318931	-1.247529
21	6	0	1.465426	-0.569240	1.059889
22	6	0	2.978418	-4.311441	-1.546348
23	6	0	0.764494	-0.532574	2.288098

24	6	0	0.853052	0.605461	3.111742
25	6	0	1.656502	1.681674	2.720927
26	6	0	2.336798	1.623868	1.520595
27	6	0	2.248026	0.518403	0.670125
28	6	0	0.095845	0.666358	4.412880
29	6	0	-0.084983	-1.693389	2.733638
30	6	0	3.017210	0.808803	-0.575424
31	6	0	3.598911	2.081881	-0.438030
32	6	0	3.209807	2.659610	0.884672
33	6	0	4.366448	2.656342	-1.433154
34	6	0	4.554637	1.935392	-2.616409
35	6	0	3.969811	0.680611	-2.770145
36	6	0	3.195294	0.100477	-1.756544
37	8	0	3.518496	3.738400	1.340819
38	1	0	-1.375506	2.651435	-1.390144
39	1	0	-6.314309	2.358853	-0.640181
40	1	0	-5.246667	4.532694	-1.292534
41	1	0	-2.812995	4.655831	-1.656696
42	1	0	-0.342726	0.197563	-0.989898
43	1	0	-4.110728	-2.825619	0.261749
44	1	0	-0.817037	-4.253706	0.869250
45	1	0	-2.564294	-4.562432	0.777595
46	1	0	-1.534573	-4.703935	-0.665716
47	1	0	2.651894	-5.083527	-2.227243
48	1	0	4.019076	-4.232920	-1.268832
49	1	0	1.739805	2.564393	3.349797
50	1	0	0.198150	1.651971	4.871177
51	1	0	-0.970288	0.466806	4.264287
52	1	0	0.468378	-0.076935	5.126530
53	1	0	0.048510	-1.885082	3.801241
54	1	0	-1.149329	-1.481569	2.569416
55	1	0	0.161434	-2.611340	2.196578
56	1	0	4.799614	3.641758	-1.290571
57	1	0	5.151547	2.354231	-3.419670
58	1	0	4.115740	0.133141	-3.695826
59	1	0	2.762534	-0.880366	-1.918257

Free Energy and Geometry for N (Conformer 2 of 4):



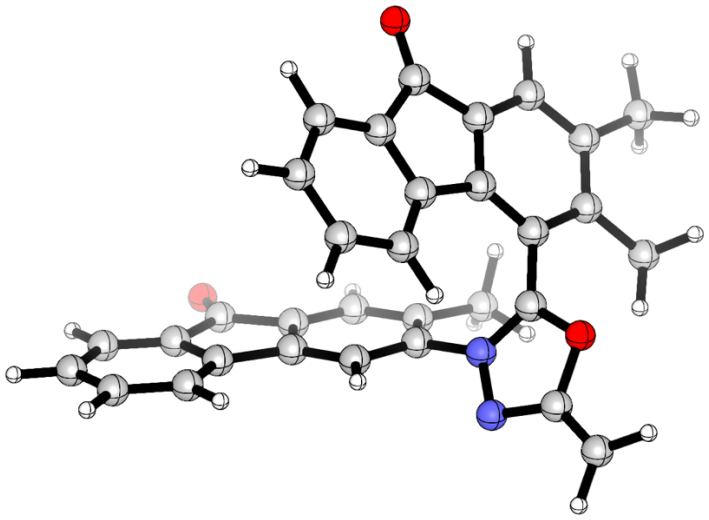
Sum of electronic and thermal free energies: -1566.767097 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-5.537893	1.141943	0.912143
2	6	0	-4.803421	0.384306	0.013898
3	6	0	-5.439649	-0.578282	-0.785699
4	6	0	-6.802514	-0.805735	-0.709781
5	6	0	-7.544675	-0.042720	0.196412
6	6	0	-6.917101	0.915672	0.992903
7	6	0	-4.419517	-1.240206	-1.657390
8	6	0	-3.115803	-0.582832	-1.301567
9	6	0	-3.354869	0.380214	-0.307198
10	6	0	-2.301557	1.118518	0.188747
11	6	0	-1.021256	0.861109	-0.325258
12	6	0	-0.762661	-0.059103	-1.346152
13	6	0	-1.860519	-0.800487	-1.823025
14	8	0	-4.595831	-2.116706	-2.473735
15	6	0	0.589120	-0.266032	-1.976564
16	7	0	0.033768	1.632243	0.263584
17	6	0	1.113986	1.180104	0.848593
18	8	0	1.786156	2.223372	1.336933
19	6	0	1.032595	3.380804	1.004944
20	7	0	-0.098112	2.985175	0.340458
21	6	0	1.612421	-0.188803	0.997231
22	6	0	1.494081	4.597473	1.341884
23	6	0	0.856442	-1.175894	1.672931
24	6	0	1.348015	-2.491833	1.768890
25	6	0	2.598640	-2.803798	1.227131
26	6	0	3.332999	-1.819138	0.596167
27	6	0	2.861409	-0.510486	0.460086

28	6	0	0.543267	-3.558390	2.464839
29	6	0	-0.467408	-0.850215	2.314464
30	6	0	3.843137	0.267605	-0.353819
31	6	0	4.916502	-0.585308	-0.669014
32	6	0	4.659598	-1.936047	-0.084934
33	6	0	5.991884	-0.174588	-1.433200
34	6	0	5.995288	1.139425	-1.910600
35	6	0	4.933061	1.990501	-1.615981
36	6	0	3.847094	1.570588	-0.835873
37	8	0	5.361324	-2.920645	-0.157853
38	1	0	-5.065543	1.892839	1.537999
39	1	0	-7.271833	-1.555288	-1.339764
40	1	0	-8.615576	-0.193857	0.282154
41	1	0	-7.510102	1.499323	1.689913
42	1	0	-2.417144	1.878376	0.954747
43	1	0	-1.715599	-1.530272	-2.615343
44	1	0	1.089767	-1.145724	-1.557361
45	1	0	0.468043	-0.432499	-3.049682
46	1	0	1.249044	0.594154	-1.838112
47	1	0	0.917070	5.473548	1.085068
48	1	0	2.427584	4.696224	1.875793
49	1	0	2.993798	-3.814107	1.295929
50	1	0	1.016714	-4.535032	2.346715
51	1	0	0.455806	-3.354530	3.537937
52	1	0	-0.473170	-3.619165	2.062991
53	1	0	-1.300004	-1.240800	1.716042
54	1	0	-0.534374	-1.310554	3.303835
55	1	0	-0.616027	0.224244	2.435946
56	1	0	6.800753	-0.864353	-1.654476
57	1	0	6.822330	1.497369	-2.514606
58	1	0	4.942351	3.007411	-1.995073
59	1	0	3.049145	2.272415	-0.622955

Free Energy and Geometry for N (Conformer 3 of 4):



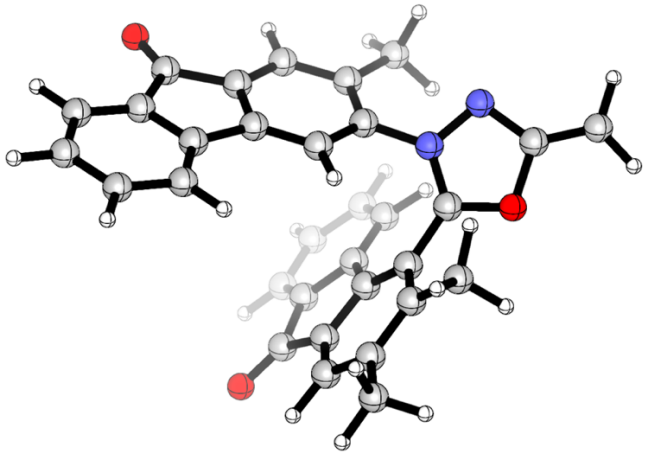
Sum of electronic and thermal free energies: -1566.767268 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-4.466892	-0.942181	1.028423
2	6	0	-3.807475	-0.574313	-0.133475
3	6	0	-4.488484	0.125046	-1.142237
4	6	0	-5.823981	0.465981	-1.020468
5	6	0	-6.491437	0.093399	0.150110
6	6	0	-5.818272	-0.599623	1.156816
7	6	0	-3.542446	0.398623	-2.269404
8	6	0	-2.234037	-0.198955	-1.834770
9	6	0	-2.404333	-0.778864	-0.567858
10	6	0	-1.337786	-1.399832	0.045295
11	6	0	-0.103153	-1.397242	-0.622026
12	6	0	0.080759	-0.867502	-1.903989
13	6	0	-1.031519	-0.247004	-2.502875
14	8	0	-3.772716	0.976032	-3.308394
15	6	0	1.365064	-0.965580	-2.683269
16	7	0	0.978463	-2.015809	0.089953
17	6	0	2.142638	-1.493639	0.387162
18	8	0	2.818935	-2.376414	1.122048
19	6	0	1.966839	-3.502252	1.285884
20	7	0	0.782209	-3.243330	0.647344
21	6	0	2.642181	-0.146301	0.096871
22	6	0	2.396708	-4.573923	1.972653
23	6	0	3.790280	0.045212	-0.705560
24	6	0	4.186777	1.347583	-1.061133
25	6	0	3.430475	2.444242	-0.629420
26	6	0	2.334466	2.237839	0.184832

27	6	0	1.946094	0.956726	0.588335
28	6	0	5.398841	1.558829	-1.929570
29	6	0	4.574826	-1.126001	-1.234625
30	6	0	0.809819	1.078815	1.542656
31	6	0	0.456985	2.436128	1.629125
32	6	0	1.395577	3.239251	0.783788
33	6	0	-0.564790	2.880646	2.447095
34	6	0	-1.250204	1.934321	3.215309
35	6	0	-0.880193	0.591547	3.167702
36	6	0	0.157987	0.147305	2.339042
37	8	0	1.405900	4.439705	0.625997
38	1	0	-3.957103	-1.481179	1.821337
39	1	0	-6.329266	1.006534	-1.815150
40	1	0	-7.539095	0.343892	0.279434
41	1	0	-6.353017	-0.879572	2.059041
42	1	0	-1.414097	-1.882220	1.013312
43	1	0	-0.939868	0.178201	-3.498874
44	1	0	1.936715	-0.033133	-2.620728
45	1	0	2.002130	-1.779579	-2.328808
46	1	0	1.137460	-1.145728	-3.736720
47	1	0	1.746558	-5.429441	2.081518
48	1	0	3.380139	-4.576285	2.418776
49	1	0	3.708334	3.453891	-0.921127
50	1	0	5.574215	2.623239	-2.097099
51	1	0	6.297089	1.133220	-1.469764
52	1	0	5.278259	1.076442	-2.906018
53	1	0	4.162867	-2.085553	-0.920512
54	1	0	4.604524	-1.104950	-2.329790
55	1	0	5.611947	-1.079781	-0.885582
56	1	0	-0.812280	3.936894	2.491318
57	1	0	-2.060101	2.246727	3.865960
58	1	0	-1.401660	-0.128672	3.790595
59	1	0	0.436684	-0.903247	2.348079

Free Energy and Geometry for N (Conformer 4 of 4):



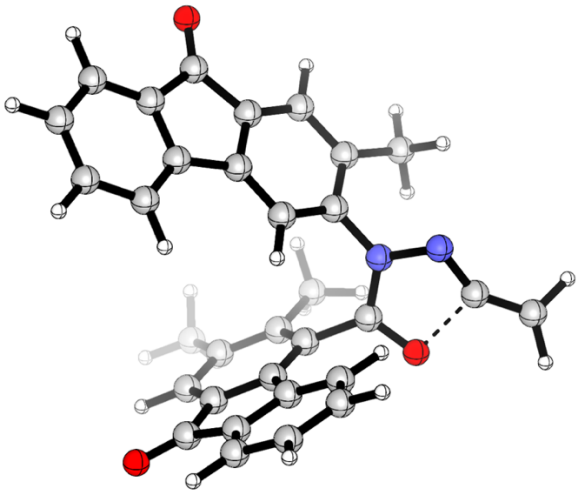
Sum of electronic and thermal free energies: -1566.766979 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-3.187073	1.665073	-1.549361
2	6	0	-3.088002	0.350489	-1.123082
3	6	0	-4.231230	-0.342878	-0.695695
4	6	0	-5.482256	0.247662	-0.686570
5	6	0	-5.584761	1.573140	-1.119892
6	6	0	-4.451173	2.267296	-1.543071
7	6	0	-3.835844	-1.727612	-0.285556
8	6	0	-2.351679	-1.792573	-0.510317
9	6	0	-1.919577	-0.555998	-1.007347
10	6	0	-0.583912	-0.371511	-1.302195
11	6	0	0.297889	-1.435799	-1.067848
12	6	0	-0.112244	-2.688337	-0.587383
13	6	0	-1.480599	-2.841569	-0.307404
14	8	0	-4.550688	-2.609107	0.135715
15	6	0	0.809210	-3.861813	-0.377132
16	7	0	1.685905	-1.197798	-1.341322
17	6	0	2.378446	-0.141785	-0.983354
18	8	0	3.615968	-0.280389	-1.458044
19	6	0	3.651293	-1.524486	-2.141204
20	7	0	2.409351	-2.096021	-2.061853
21	6	0	1.947287	1.061007	-0.261445
22	6	0	4.789507	-1.939174	-2.723443
23	6	0	2.003371	2.314139	-0.920444
24	6	0	1.526861	3.468337	-0.273734
25	6	0	0.957703	3.360432	1.001743
26	6	0	0.913714	2.131178	1.626629
27	6	0	1.432880	0.977052	1.030387
28	6	0	1.600167	4.814633	-0.948050

29	6	0	2.552270	2.416455	-2.321224
30	6	0	1.295519	-0.153950	1.988062
31	6	0	0.616706	0.312429	3.126359
32	6	0	0.347393	1.775077	2.966451
33	6	0	0.334688	-0.508331	4.202453
34	6	0	0.754182	-1.841049	4.141247
35	6	0	1.460152	-2.303480	3.032124
36	6	0	1.745519	-1.464901	1.947674
37	8	0	-0.201930	2.517314	3.749896
38	1	0	-2.314317	2.221498	-1.878245
39	1	0	-6.351945	-0.309067	-0.350939
40	1	0	-6.550364	2.067676	-1.126308
41	1	0	-4.550041	3.296466	-1.873580
42	1	0	-0.212101	0.561073	-1.713251
43	1	0	-1.848256	-3.790061	0.074769
44	1	0	0.370662	-4.541989	0.356979
45	1	0	0.950062	-4.404478	-1.316335
46	1	0	1.802579	-3.565517	-0.041484
47	1	0	4.808539	-2.892157	-3.231218
48	1	0	5.676140	-1.323928	-2.685168
49	1	0	0.556083	4.238052	1.501864
50	1	0	1.291129	5.604382	-0.260399
51	1	0	2.616862	5.035663	-1.287646
52	1	0	0.947111	4.860337	-1.826764
53	1	0	2.027325	3.185855	-2.890668
54	1	0	3.614587	2.685838	-2.301796
55	1	0	2.465802	1.475155	-2.867851
56	1	0	-0.191180	-0.116943	5.068004
57	1	0	0.545636	-2.514325	4.965937
58	1	0	1.803464	-3.333180	3.006539
59	1	0	2.330178	-1.841066	1.114976

Free Energy and Geometry for S-TS1:



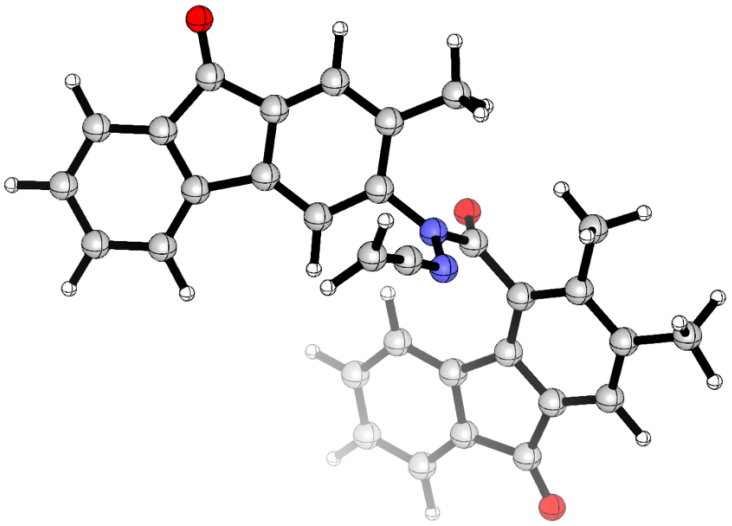
Sum of electronic and thermal free energies: -1566.752062 a.u.

Number of imaginary frequencies: 1

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-2.631684	2.292615	-0.882235
2	6	0	-3.026534	0.987056	-0.639081
3	6	0	-4.378386	0.687122	-0.409882
4	6	0	-5.355314	1.666336	-0.420515
5	6	0	-4.959460	2.984424	-0.668938
6	6	0	-3.616843	3.287854	-0.895007
7	6	0	-4.515077	-0.784455	-0.168944
8	6	0	-3.120243	-1.330969	-0.277833
9	6	0	-2.245792	-0.271950	-0.557098
10	6	0	-0.895092	-0.521985	-0.713656
11	6	0	-0.453665	-1.841188	-0.558986
12	6	0	-1.313561	-2.916105	-0.289073
13	6	0	-2.679576	-2.634127	-0.150155
14	8	0	-5.527578	-1.406194	0.065072
15	6	0	-0.784815	-4.318336	-0.158824
16	7	0	0.937883	-2.122916	-0.696054
17	6	0	1.943726	-1.544986	-0.033720
18	8	0	3.091779	-1.929062	-0.386312
19	6	0	2.617126	-3.167779	-1.620215
20	7	0	1.382567	-2.841379	-1.808776
21	6	0	1.725496	-0.500757	0.997517
22	6	0	3.601549	-4.004766	-1.916988
23	6	0	1.276791	-0.846241	2.286610
24	6	0	1.087290	0.161745	3.251473
25	6	0	1.360987	1.494811	2.922803
26	6	0	1.802165	1.807647	1.651219
27	6	0	1.988104	0.824557	0.676097

28	6	0	0.585746	-0.185367	4.629297
29	6	0	0.969651	-2.283463	2.619935
30	6	0	2.385122	1.474619	-0.601639
31	6	0	2.458406	2.860483	-0.378728
32	6	0	2.107390	3.145216	1.049576
33	6	0	2.786262	3.748775	-1.385204
34	6	0	3.042529	3.231529	-2.659808
35	6	0	2.961521	1.860014	-2.891326
36	6	0	2.632452	0.961066	-1.867387
37	8	0	2.064703	4.224372	1.597448
38	1	0	-1.590140	2.546453	-1.056907
39	1	0	-6.394941	1.410000	-0.240158
40	1	0	-5.698939	3.778121	-0.685250
41	1	0	-3.328309	4.317050	-1.083922
42	1	0	-0.186566	0.261634	-0.965460
43	1	0	-3.384080	-3.433574	0.062992
44	1	0	0.090079	-4.352080	0.498598
45	1	0	-1.552310	-4.979963	0.247221
46	1	0	-0.466605	-4.703825	-1.132203
47	1	0	3.350764	-5.009845	-2.229967
48	1	0	4.636015	-3.697549	-1.857203
49	1	0	1.215955	2.282466	3.657617
50	1	0	0.408831	0.720188	5.213002
51	1	0	-0.351180	-0.749760	4.582180
52	1	0	1.309687	-0.801305	5.174154
53	1	0	1.235455	-2.516458	3.653287
54	1	0	-0.103213	-2.485505	2.502358
55	1	0	1.515513	-2.975222	1.973227
56	1	0	2.835871	4.814507	-1.183152
57	1	0	3.301816	3.899861	-3.474099
58	1	0	3.158276	1.474430	-3.886548
59	1	0	2.586006	-0.102857	-2.081333

Free Energy and Geometry O (Conformer 1 of 17):



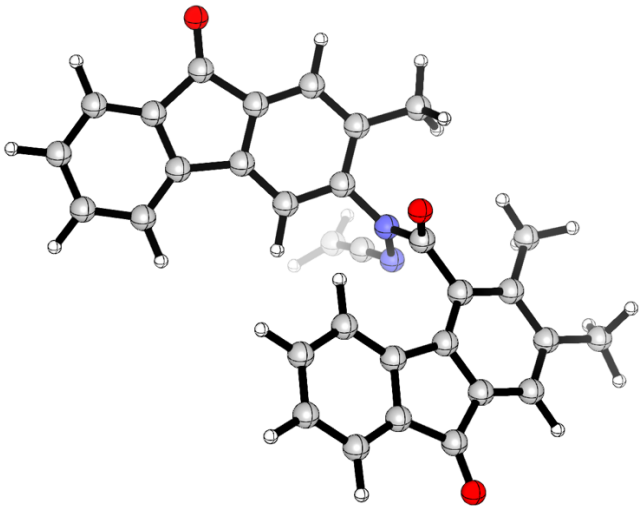
Sum of electronic and thermal free energies: -1566.781697 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	4.168414	2.108462	1.085635
2	6	0	4.250822	0.898862	0.414739
3	6	0	5.486540	0.444907	-0.072680
4	6	0	6.650593	1.173127	0.094459
5	6	0	6.568934	2.394121	0.771384
6	6	0	5.343732	2.850358	1.257521
7	6	0	5.285683	-0.875517	-0.749542
8	6	0	3.817446	-1.163069	-0.620671
9	6	0	3.212577	-0.105592	0.073207
10	8	0	6.122456	-1.567502	-1.285671
11	6	0	1.851157	-0.141548	0.316026
12	6	0	1.130054	-1.248245	-0.148289
13	6	0	1.720649	-2.315830	-0.834044
14	6	0	3.100756	-2.253088	-1.074139
15	6	0	0.893313	-3.482006	-1.298982
16	7	0	-0.276441	-1.283249	0.136091
17	6	0	-1.204322	-0.966669	-0.834891
18	7	0	-0.735206	-1.516854	1.422473
19	6	0	0.062340	-1.803653	2.321373
20	6	0	0.810994	-2.100884	3.349541
21	8	0	-0.856517	-0.780369	-1.986818
22	6	0	-2.626835	-0.795072	-0.381603
23	6	0	-3.457842	-1.894499	-0.100644
24	6	0	-4.798308	-1.688890	0.275038
25	6	0	-5.296094	-0.384348	0.370989

26	6	0	-4.463484	0.681290	0.090580
27	6	0	-3.131051	0.495810	-0.295668
28	6	0	-2.499936	1.832066	-0.497035
29	6	0	-3.464984	2.815123	-0.218319
30	6	0	-4.751038	2.146850	0.156158
31	6	0	-2.910279	-3.295547	-0.173232
32	6	0	-5.690241	-2.863292	0.584074
33	8	0	-5.797964	2.680299	0.454475
34	6	0	-3.188010	4.166776	-0.300729
35	6	0	-1.896481	4.551503	-0.673842
36	6	0	-0.933545	3.584691	-0.956387
37	6	0	-1.220400	2.215400	-0.876121
38	1	0	3.223157	2.479437	1.470402
39	1	0	7.594098	0.799817	-0.292269
40	1	0	7.461921	2.992023	0.920208
41	1	0	5.299050	3.800744	1.780124
42	1	0	1.330447	0.653576	0.843586
43	1	0	3.602995	-3.055641	-1.607686
44	1	0	0.169169	-3.158985	-2.054594
45	1	0	1.527415	-4.255751	-1.736122
46	1	0	0.336554	-3.923330	-0.465351
47	1	0	1.216265	-1.315208	3.977838
48	1	0	1.047804	-3.133864	3.578883
49	1	0	-6.326040	-0.206985	0.670028
50	1	0	-3.606686	-3.967188	-0.682898
51	1	0	-1.958530	-3.333640	-0.707446
52	1	0	-2.745129	-3.694486	0.834888
53	1	0	-6.666210	-2.524686	0.938198
54	1	0	-5.851062	-3.486635	-0.302751
55	1	0	-5.251671	-3.506082	1.354715
56	1	0	-3.959111	4.898674	-0.079261
57	1	0	-1.642605	5.603735	-0.748614
58	1	0	0.063247	3.896350	-1.253082
59	1	0	-0.454259	1.489838	-1.128074

Free Energy and Geometry O (Conformer 2 of 17):



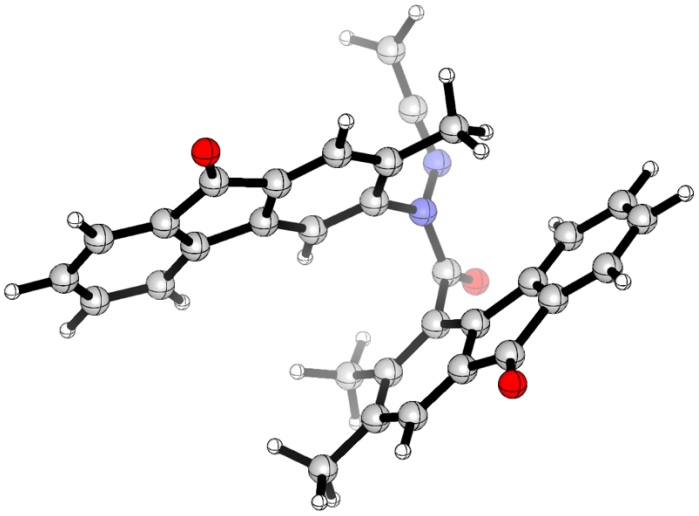
Sum of electronic and thermal free energies: -1566.781682 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-4.168340	2.108505	1.085246
2	6	0	-4.250756	0.898781	0.414579
3	6	0	-5.486490	0.444702	-0.072688
4	6	0	-6.650546	1.172932	0.094365
5	6	0	-6.568880	2.394056	0.771057
6	6	0	-5.343667	2.850408	1.257053
7	6	0	-5.285638	-0.875854	-0.749302
8	6	0	-3.817382	-1.163332	-0.620475
9	6	0	-3.212507	-0.105714	0.073174
10	8	0	-6.122419	-1.567939	-1.285284
11	6	0	-1.851072	-0.141583	0.315925
12	6	0	-1.129951	-1.248331	-0.148233
13	6	0	-1.720558	-2.316074	-0.833761
14	6	0	-3.100677	-2.253412	-1.073776
15	6	0	-0.893270	-3.482409	-1.298392
16	7	0	0.276554	-1.283204	0.136099
17	6	0	1.204423	-0.966827	-0.834957
18	7	0	0.735378	-1.516324	1.422546
19	6	0	-0.062077	-1.802766	2.321649
20	6	0	-0.810578	-2.099658	3.350021
21	8	0	0.856661	-0.780951	-1.986967
22	6	0	2.626925	-0.795093	-0.381688
23	6	0	3.458049	-1.894445	-0.100734
24	6	0	4.798476	-1.688682	0.274977
25	6	0	5.296126	-0.384077	0.370926
26	6	0	4.463413	0.681465	0.090500

27	6	0	3.130996	0.495818	-0.295748
28	6	0	2.499710	1.831971	-0.497145
29	6	0	3.464604	2.815167	-0.218406
30	6	0	4.750759	2.147073	0.156066
31	6	0	2.910568	-3.295529	-0.173258
32	6	0	5.690538	-2.862980	0.584053
33	8	0	5.797597	2.680675	0.454413
34	6	0	3.187405	4.166773	-0.300829
35	6	0	1.895822	4.551283	-0.673978
36	6	0	0.933044	3.584318	-0.956555
37	6	0	1.220123	2.215078	-0.876277
38	1	0	-3.223075	2.479568	1.469906
39	1	0	-7.594065	0.799529	-0.292241
40	1	0	-7.461872	2.991969	0.919808
41	1	0	-5.298982	3.800891	1.779480
42	1	0	-1.330366	0.653684	0.843278
43	1	0	-3.602928	-3.056096	-1.607117
44	1	0	-1.527412	-4.256227	-1.735342
45	1	0	-0.169099	-3.159617	-2.054069
46	1	0	-0.336556	-3.923554	-0.464634
47	1	0	-1.047356	-3.132557	3.579752
48	1	0	-1.215799	-1.313754	3.978068
49	1	0	6.326056	-0.206622	0.669969
50	1	0	1.958999	-3.333753	-0.707786
51	1	0	3.607164	-3.967239	-0.682575
52	1	0	2.745097	-3.694303	0.834874
53	1	0	6.666396	-2.524261	0.938374
54	1	0	5.251928	-3.505905	1.354557
55	1	0	5.851607	-3.486217	-0.302802
56	1	0	3.958372	4.898809	-0.079346
57	1	0	1.641782	5.603476	-0.748761
58	1	0	-0.063790	3.895823	-1.253271
59	1	0	0.454116	1.489380	-1.128256

Free Energy and Geometry O (Conformer 3 of 17):



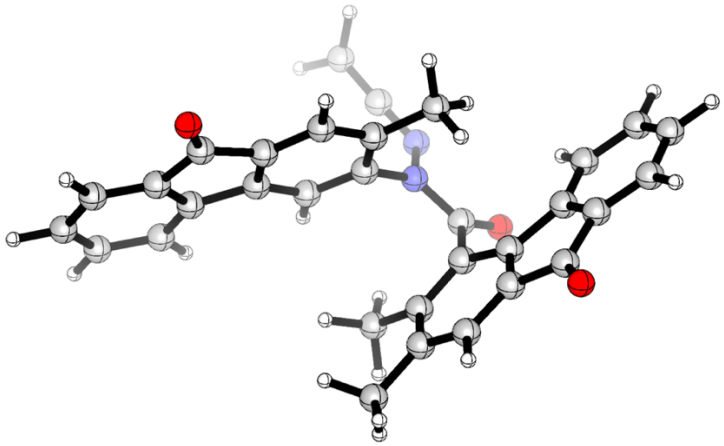
Sum of electronic and thermal free energies: -1566.776326 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	4.417940	-0.443459	1.013314
2	6	0	3.699901	0.119105	-0.030181
3	6	0	4.278962	0.231024	-1.304234
4	6	0	5.564246	-0.209239	-1.564875
5	6	0	6.288689	-0.778594	-0.513189
6	6	0	5.719513	-0.891076	0.755284
7	6	0	3.294100	0.872433	-2.232040
8	6	0	2.073878	1.123886	-1.393955
9	6	0	2.324588	0.673784	-0.088915
10	8	0	3.444636	1.136199	-3.404255
11	6	0	1.342082	0.803970	0.871849
12	6	0	0.105201	1.354316	0.499685
13	6	0	-0.147871	1.831657	-0.792974
14	6	0	0.874960	1.703578	-1.748525
15	6	0	-1.452896	2.465625	-1.197982
16	7	0	-0.902285	1.458537	1.520739
17	6	0	-1.446426	0.358846	2.179698
18	7	0	-1.169090	2.687166	2.113483
19	6	0	-0.623133	3.708317	1.685404
20	6	0	-0.118164	4.851204	1.302737
21	8	0	-2.070181	0.456896	3.214405
22	6	0	-1.254659	-0.939012	1.440459
23	6	0	-0.308079	-1.895196	1.852209
24	6	0	-0.092767	-3.051511	1.076844
25	6	0	-0.831142	-3.249283	-0.095706
26	6	0	-1.795034	-2.325833	-0.451788

27	6	0	-2.034269	-1.183343	0.317883
28	6	0	-3.162842	-0.424316	-0.284079
29	6	0	-3.536770	-1.069211	-1.474958
30	6	0	-2.701404	-2.302323	-1.643178
31	6	0	0.494316	-1.695250	3.111850
32	6	0	0.944904	-4.059204	1.496543
33	8	0	-2.751866	-3.108561	-2.546153
34	6	0	-4.567389	-0.602956	-2.269781
35	6	0	-5.256365	0.539491	-1.848249
36	6	0	-4.918869	1.160012	-0.646505
37	6	0	-3.873576	0.683572	0.155336
38	1	0	3.994663	-0.534883	2.009244
39	1	0	5.988622	-0.111328	-2.559543
40	1	0	7.299447	-1.135030	-0.681599
41	1	0	6.297220	-1.333888	1.560553
42	1	0	1.497772	0.498939	1.902365
43	1	0	0.716038	2.056166	-2.764678
44	1	0	-2.103034	2.662796	-0.345560
45	1	0	-1.999829	1.812740	-1.887294
46	1	0	-1.260463	3.410378	-1.715497
47	1	0	0.805871	5.218100	1.735008
48	1	0	-0.614966	5.440524	0.539550
49	1	0	-0.656765	-4.124726	-0.715884
50	1	0	1.569711	-1.697903	2.900411
51	1	0	0.238003	-0.764776	3.622012
52	1	0	0.308928	-2.514949	3.814483
53	1	0	0.978654	-4.895715	0.795579
54	1	0	1.943293	-3.608424	1.534697
55	1	0	0.733830	-4.459176	2.494298
56	1	0	-4.833427	-1.121690	-3.185971
57	1	0	-6.069981	0.934259	-2.447757
58	1	0	-5.480035	2.029880	-0.319708
59	1	0	-3.644392	1.176422	1.095890

Free Energy and Geometry O (Conformer 4 of 17):



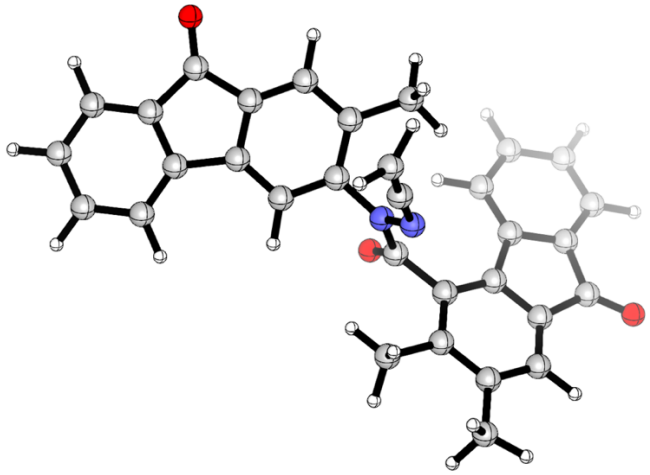
Sum of electronic and thermal free energies: -1566.776699 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	5.060970	0.032656	1.188785
2	6	0	4.270731	-0.059124	0.053998
3	6	0	4.790320	-0.617419	-1.124692
4	6	0	6.089459	-1.086915	-1.200401
5	6	0	6.888376	-0.993149	-0.056752
6	6	0	6.376671	-0.441406	1.117935
7	6	0	3.729616	-0.598482	-2.181018
8	6	0	2.530036	0.018720	-1.520218
9	6	0	2.863037	0.339523	-0.194950
10	8	0	3.813705	-0.993029	-3.322668
11	6	0	1.914737	0.924689	0.619459
12	6	0	0.632440	1.158249	0.095154
13	6	0	0.302894	0.885069	-1.238631
14	6	0	1.285715	0.287121	-2.047170
15	6	0	-1.044236	1.209553	-1.820883
16	7	0	-0.317126	1.798170	0.963601
17	6	0	-1.361426	1.169275	1.624981
18	7	0	-0.186323	3.156859	1.228602
19	6	0	0.685900	3.813386	0.652082
20	6	0	1.575318	4.603350	0.111452
21	8	0	-2.102177	1.761256	2.382361
22	6	0	-1.553106	-0.286111	1.289257
23	6	0	-0.694623	-1.282732	1.796270
24	6	0	-0.895228	-2.633574	1.453868
25	6	0	-1.963820	-2.982448	0.622437
26	6	0	-2.827564	-1.998894	0.182588
27	6	0	-2.656173	-0.651544	0.522366
28	6	0	-3.770118	0.136585	-0.087931

29	6	0	-4.579239	-0.749266	-0.820443
30	6	0	-4.035354	-2.135397	-0.687451
31	6	0	0.418010	-0.935968	2.751459
32	6	0	0.029272	-3.696739	1.985968
33	8	0	-4.476027	-3.152018	-1.179200
34	6	0	-5.697423	-0.328359	-1.516232
35	6	0	-6.021538	1.030703	-1.478813
36	6	0	-5.232463	1.916087	-0.747060
37	6	0	-4.102777	1.484325	-0.039604
38	1	0	4.679462	0.458256	2.112110
39	1	0	6.467606	-1.513868	-2.124398
40	1	0	7.912061	-1.351677	-0.079966
41	1	0	7.011032	-0.378153	1.996503
42	1	0	2.127564	1.203508	1.647540
43	1	0	1.066656	0.049497	-3.085056
44	1	0	-1.674311	0.314746	-1.870657
45	1	0	-0.930414	1.588170	-2.839989
46	1	0	-1.574761	1.959157	-1.229705
47	1	0	1.360463	5.119253	-0.817593
48	1	0	2.543048	4.742253	0.580651
49	1	0	-2.127794	-4.018311	0.336499
50	1	0	1.397167	-1.197277	2.334528
51	1	0	0.426300	0.124654	3.011096
52	1	0	0.302070	-1.501822	3.682060
53	1	0	-0.238203	-4.676973	1.586241
54	1	0	1.071272	-3.491552	1.717766
55	1	0	-0.016039	-3.753207	3.079386
56	1	0	-6.298382	-1.043290	-2.070258
57	1	0	-6.891233	1.397955	-2.013520
58	1	0	-5.500238	2.967677	-0.716527
59	1	0	-3.523679	2.195544	0.539055

Free Energy and Geometry O (Conformer 5 of 17):



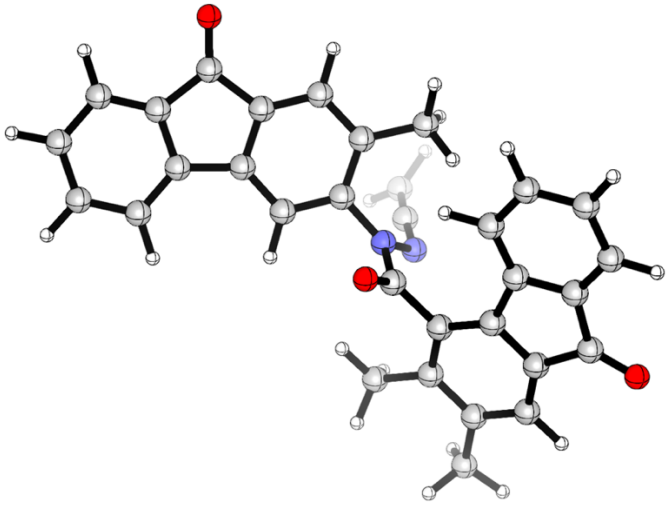
Sum of electronic and thermal free energies: -1566.780383 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	5.057885	1.685320	-1.497565
2	6	0	4.788523	0.554936	-0.742731
3	6	0	5.812893	-0.359505	-0.451193
4	6	0	7.109069	-0.172056	-0.896821
5	6	0	7.382373	0.968659	-1.657935
6	6	0	6.368162	1.880327	-1.951322
7	6	0	5.247228	-1.477301	0.368437
8	6	0	3.793645	-1.142007	0.538298
9	6	0	3.530554	0.066687	-0.124386
10	8	0	5.830801	-2.444918	0.804513
11	6	0	2.251940	0.589507	-0.106156
12	6	0	1.257735	-0.124557	0.575279
13	6	0	1.500298	-1.340041	1.229199
14	6	0	2.810302	-1.844383	1.203217
15	6	0	0.406721	-2.091867	1.940373
16	7	0	-0.063495	0.428965	0.611227
17	6	0	-0.833483	0.506715	-0.534802
18	7	0	-0.600682	0.927645	1.784667
19	6	0	0.070886	0.950447	2.820979
20	6	0	0.677641	1.017974	3.976150
21	8	0	-0.404012	0.106893	-1.600529
22	6	0	-2.226994	1.044843	-0.376643
23	6	0	-2.472399	2.416793	-0.179670
24	6	0	-3.793674	2.891622	-0.085852
25	6	0	-4.859698	1.990020	-0.179833
26	6	0	-4.597286	0.648392	-0.374958
27	6	0	-3.290792	0.159103	-0.490430

28	6	0	-3.349036	-1.321070	-0.670543
29	6	0	-4.699755	-1.709406	-0.643684
30	6	0	-5.555771	-0.494673	-0.468245
31	6	0	-1.329748	3.390029	-0.049153
32	6	0	-4.060155	4.358866	0.127927
33	8	0	-6.765765	-0.448561	-0.408842
34	6	0	-5.092875	-3.028440	-0.770173
35	6	0	-4.098452	-3.998834	-0.927420
36	6	0	-2.756950	-3.624315	-0.963028
37	6	0	-2.363678	-2.284540	-0.841905
38	1	0	4.280361	2.404307	-1.737097
39	1	0	7.883328	-0.894971	-0.658052
40	1	0	8.387698	1.147557	-2.024593
41	1	0	6.598389	2.759615	-2.544771
42	1	0	1.995519	1.519650	-0.604403
43	1	0	3.045005	-2.785082	1.694679
44	1	0	-0.576125	-1.881217	1.510059
45	1	0	0.370446	-1.818937	3.001053
46	1	0	0.588183	-3.167727	1.883327
47	1	0	1.265222	1.890727	4.238518
48	1	0	0.610442	0.197908	4.683175
49	1	0	-5.886131	2.337776	-0.094538
50	1	0	-1.260768	3.763298	0.979205
51	1	0	-0.368985	2.937906	-0.304298
52	1	0	-1.476319	4.255449	-0.702388
53	1	0	-5.129768	4.544326	0.246076
54	1	0	-3.548175	4.731582	1.021612
55	1	0	-3.705200	4.956698	-0.719095
56	1	0	-6.146410	-3.290825	-0.745651
57	1	0	-4.369618	-5.044622	-1.027446
58	1	0	-1.994330	-4.385563	-1.095254
59	1	0	-1.312366	-2.024911	-0.904970

Free Energy and Geometry O (Conformer 6 of 17):



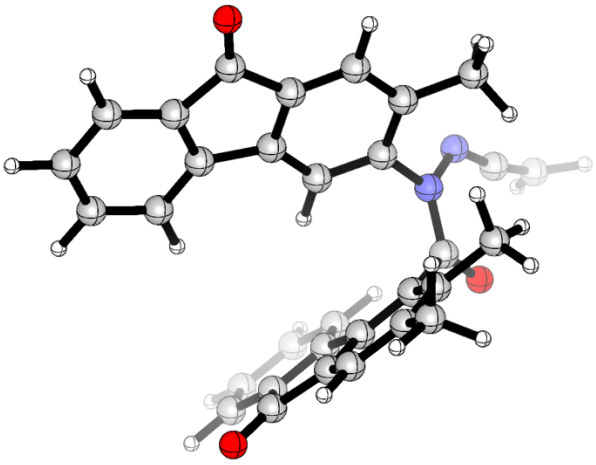
Sum of electronic and thermal free energies: -1566.780391 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-5.057301	1.685540	-1.497689
2	6	0	-4.788272	0.555064	-0.742877
3	6	0	-5.812883	-0.359124	-0.451410
4	6	0	-7.108992	-0.171329	-0.897089
5	6	0	-7.381967	0.969485	-1.658170
6	6	0	-6.367511	1.880902	-1.951487
7	6	0	-5.247507	-1.477133	0.368140
8	6	0	-3.793839	-1.142214	0.538039
9	6	0	-3.530444	0.066440	-0.124535
10	8	0	-5.831329	-2.444625	0.804153
11	6	0	-2.251718	0.589018	-0.106159
12	6	0	-1.257735	-0.125275	0.575319
13	6	0	-1.500612	-1.340756	1.229176
14	6	0	-2.810698	-1.844819	1.203043
15	6	0	-0.407245	-2.092780	1.940450
16	7	0	0.063618	0.427937	0.611477
17	6	0	0.833459	0.506521	-0.534564
18	7	0	0.600647	0.926720	1.785023
19	6	0	-0.071021	0.949260	2.821264
20	6	0	-0.677872	1.016434	3.976413
21	8	0	0.404037	0.107115	-1.600473
22	6	0	2.226867	1.044880	-0.376255
23	6	0	2.472041	2.416815	-0.179008
24	6	0	3.793236	2.891876	-0.085220
25	6	0	4.859412	1.990490	-0.179498
26	6	0	4.597219	0.648850	-0.374876

27	6	0	3.290812	0.159340	-0.490297
28	6	0	3.349305	-1.320784	-0.670685
29	6	0	4.700092	-1.708881	-0.644051
30	6	0	5.555910	-0.494020	-0.468500
31	6	0	1.329187	3.389798	-0.048373
32	6	0	4.059463	4.359142	0.128717
33	8	0	6.765899	-0.447699	-0.409199
34	6	0	5.093432	-3.027823	-0.770850
35	6	0	4.099161	-3.998354	-0.928173
36	6	0	2.757587	-3.624067	-0.963539
37	6	0	2.364092	-2.284391	-0.842098
38	1	0	-4.279574	2.404324	-1.737173
39	1	0	-7.883450	-0.894054	-0.658394
40	1	0	-8.387231	1.148654	-2.024862
41	1	0	-6.597492	2.760267	-2.544918
42	1	0	-1.995093	1.519119	-0.604367
43	1	0	-3.045664	-2.785496	1.694423
44	1	0	-0.370822	-1.819607	3.001066
45	1	0	-0.589063	-3.168593	1.883686
46	1	0	0.575639	-1.882527	1.510037
47	1	0	-0.610416	0.196267	4.683303
48	1	0	-1.265680	1.888985	4.238927
49	1	0	5.885795	2.338401	-0.094240
50	1	0	1.475682	4.255432	-0.701343
51	1	0	0.368568	2.937525	-0.303804
52	1	0	1.259938	3.762757	0.980077
53	1	0	5.129018	4.544736	0.247190
54	1	0	3.704696	4.956938	-0.718416
55	1	0	3.547172	4.731785	1.022246
56	1	0	6.147017	-3.290023	-0.746492
57	1	0	4.370493	-5.044075	-1.028461
58	1	0	1.995091	-4.385429	-1.095820
59	1	0	1.312724	-2.024934	-0.904947

Free Energy and Geometry O (Conformer 7 of 17):



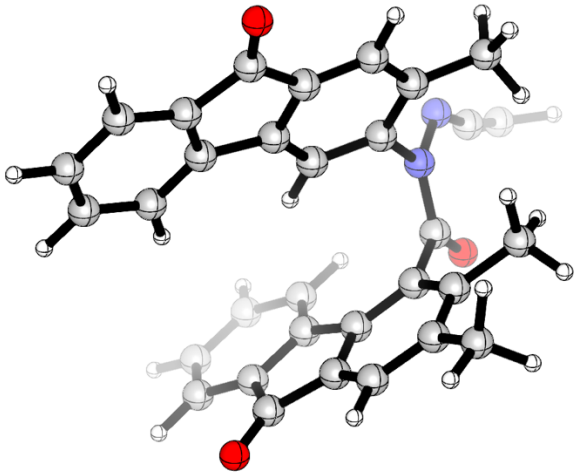
Sum of electronic and thermal free energies: -1566.778183 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	2.908558	1.483763	-1.159664
2	6	0	2.928972	0.130953	-0.860684
3	6	0	4.146894	-0.523870	-0.619982
4	6	0	5.357428	0.142997	-0.678940
5	6	0	5.340115	1.507026	-0.987499
6	6	0	4.131510	2.163248	-1.221384
7	6	0	3.870409	-1.961494	-0.301078
8	6	0	2.377353	-2.098927	-0.374968
9	6	0	1.830078	-0.853981	-0.713831
10	8	0	4.674244	-2.828722	-0.038228
11	6	0	0.463100	-0.724698	-0.858164
12	6	0	-0.340652	-1.845884	-0.613823
13	6	0	0.190833	-3.102276	-0.284712
14	6	0	1.585911	-3.211633	-0.172055
15	6	0	-0.684572	-4.309023	-0.074964
16	7	0	-1.762709	-1.691989	-0.721813
17	6	0	-2.505497	-0.792748	0.025137
18	7	0	-2.333266	-2.480272	-1.701168
19	6	0	-3.538684	-2.507578	-1.978036
20	6	0	-4.732176	-2.731648	-2.463894
21	8	0	-3.695956	-0.641689	-0.169246
22	6	0	-1.751205	-0.015422	1.070472
23	6	0	-1.375247	-0.614189	2.287459
24	6	0	-0.667702	0.129422	3.251748
25	6	0	-0.344656	1.465645	2.992808
26	6	0	-0.740032	2.039977	1.800058
27	6	0	-1.455662	1.321813	0.836775

28	6	0	-1.679209	2.198791	-0.347506
29	6	0	-1.081094	3.444217	-0.087012
30	6	0	-0.470638	3.416467	1.280138
31	6	0	-1.706244	-2.058104	2.562028
32	6	0	-0.248791	-0.511176	4.549250
33	8	0	0.123993	4.312088	1.839042
34	6	0	-1.098354	4.476457	-1.005811
35	6	0	-1.734122	4.254423	-2.231998
36	6	0	-2.332033	3.024658	-2.498468
37	6	0	-2.316800	1.981850	-1.561778
38	1	0	1.975165	2.010812	-1.337470
39	1	0	6.287418	-0.384107	-0.488110
40	1	0	6.271012	2.061591	-1.042476
41	1	0	4.137954	3.223505	-1.453894
42	1	0	0.003064	0.211837	-1.159079
43	1	0	2.037910	-4.166056	0.085320
44	1	0	-0.946879	-4.766434	-1.034115
45	1	0	-0.163081	-5.054296	0.530006
46	1	0	-1.621775	-4.048043	0.422811
47	1	0	-5.119724	-2.121364	-3.271373
48	1	0	-5.371506	-3.485838	-2.019732
49	1	0	0.217966	2.048075	3.717880
50	1	0	-2.475051	-2.438025	1.885280
51	1	0	-0.813595	-2.687815	2.455339
52	1	0	-2.073813	-2.187351	3.583698
53	1	0	0.368516	0.172565	5.135448
54	1	0	-1.118326	-0.785630	5.157062
55	1	0	0.325984	-1.426869	4.375444
56	1	0	-0.628141	5.426995	-0.772151
57	1	0	-1.765927	5.041809	-2.977691
58	1	0	-2.827259	2.868387	-3.451606
59	1	0	-2.813060	1.044333	-1.789998

Free Energy and Geometry O (Conformer 8 of 17):



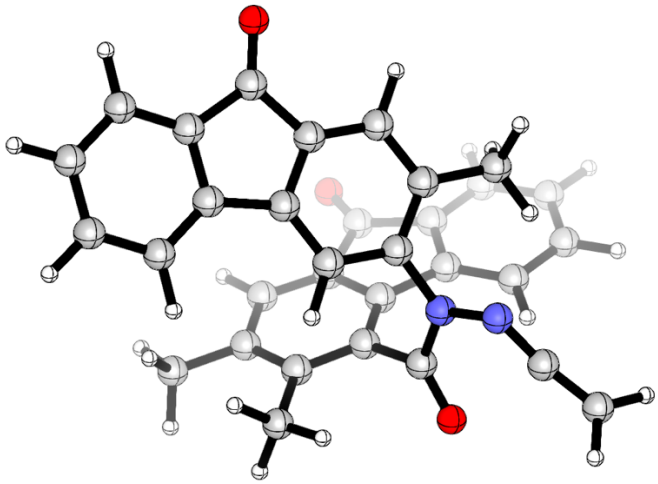
Sum of electronic and thermal free energies: -1566.778191 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	2.907616	1.485929	-1.159596
2	6	0	2.929110	0.133141	-0.860586
3	6	0	4.147554	-0.520730	-0.619957
4	6	0	5.357560	0.147090	-0.678982
5	6	0	5.339163	1.511099	-0.987550
6	6	0	4.130030	2.166371	-1.221392
7	6	0	3.872222	-1.958589	-0.301091
8	6	0	2.379240	-2.097171	-0.374798
9	6	0	1.830968	-0.852634	-0.713642
10	8	0	4.676738	-2.825176	-0.038260
11	6	0	0.463892	-0.724415	-0.857912
12	6	0	-0.338940	-1.846266	-0.613562
13	6	0	0.193515	-3.102233	-0.284454
14	6	0	1.588701	-3.210487	-0.171862
15	6	0	-0.680948	-4.309642	-0.074624
16	7	0	-1.761155	-1.693549	-0.721573
17	6	0	-2.504676	-0.794877	0.025319
18	7	0	-2.331027	-2.482196	-1.701016
19	6	0	-3.536426	-2.510296	-1.977952
20	6	0	-4.729669	-2.735354	-2.463900
21	8	0	-3.695265	-0.644826	-0.169089
22	6	0	-1.751080	-0.016769	1.070552
23	6	0	-1.374556	-0.615012	2.287627
24	6	0	-0.667837	0.129458	3.251853
25	6	0	-0.346227	1.466002	2.992768
26	6	0	-0.742140	2.039786	1.799934
27	6	0	-1.456933	1.320740	0.836692

28	6	0	-1.681338	2.197318	-0.347725
29	6	0	-1.084520	3.443395	-0.087383
30	6	0	-0.474223	3.416530	1.279873
31	6	0	-1.703978	-2.059290	2.562185
32	6	0	-0.248173	-0.510578	4.549387
33	8	0	0.119445	4.312847	1.838664
34	6	0	-1.102762	4.475461	-1.006358
35	6	0	-1.738214	4.252573	-2.232554
36	6	0	-2.334853	3.022155	-2.498862
37	6	0	-2.318627	1.979518	-1.561998
38	1	0	1.973794	2.012228	-1.337365
39	1	0	6.287972	-0.379290	-0.488192
40	1	0	6.269616	2.066405	-1.042577
41	1	0	4.135646	3.226631	-1.453917
42	1	0	0.003061	0.211741	-1.158788
43	1	0	2.041446	-4.164557	0.085530
44	1	0	-0.159036	-5.054322	0.530717
45	1	0	-0.942511	-4.767546	-1.033748
46	1	0	-1.618539	-4.049299	0.422738
47	1	0	-5.117643	-2.125294	-3.271350
48	1	0	-5.368527	-3.489902	-2.019672
49	1	0	0.215716	2.049122	3.717815
50	1	0	-2.472871	-2.439799	1.885863
51	1	0	-0.810786	-2.688109	2.454704
52	1	0	-2.070697	-2.189140	3.584072
53	1	0	0.367972	0.174080	5.135738
54	1	0	-1.117361	-0.786460	5.157040
55	1	0	0.328076	-1.425355	4.375586
56	1	0	-0.633548	5.426519	-0.772793
57	1	0	-1.770778	5.039792	-2.978390
58	1	0	-2.829845	2.865224	-3.452014
59	1	0	-2.813925	1.041453	-1.790069

Free Energy and Geometry O (Conformer 9 of 17):



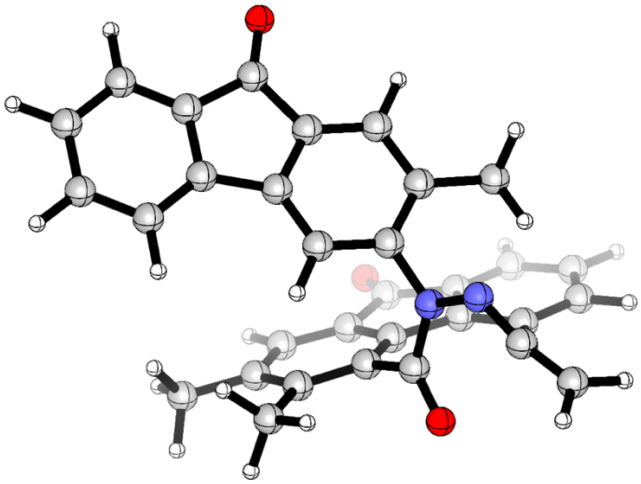
Sum of electronic and thermal free energies: -1566.775081 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-4.334174	0.672650	1.035780
2	6	0	-3.670852	0.508616	-0.170085
3	6	0	-4.349058	-0.015473	-1.281957
4	6	0	-5.681593	-0.381523	-1.219993
5	6	0	-6.351827	-0.215952	-0.003958
6	6	0	-5.683332	0.303814	1.104510
7	6	0	-3.402120	-0.086588	-2.440486
8	6	0	-2.098427	0.436272	-1.912219
9	6	0	-2.268274	0.789073	-0.565226
10	8	0	-3.634895	-0.478842	-3.562413
11	6	0	-1.201478	1.310468	0.137561
12	6	0	0.037308	1.436126	-0.510122
13	6	0	0.217101	1.102325	-1.858811
14	6	0	-0.892723	0.598236	-2.559457
15	6	0	1.529281	1.243781	-2.585398
16	7	0	1.136809	1.946878	0.263920
17	6	0	1.577748	1.361544	1.444425
18	7	0	1.541936	3.214413	-0.114528
19	6	0	2.506773	3.810225	0.381310
20	6	0	3.472884	4.624119	0.719542
21	8	0	2.316546	1.947594	2.210503
22	6	0	1.131376	-0.062775	1.630780
23	6	0	0.142350	-0.418154	2.566143
24	6	0	-0.321614	-1.746784	2.626087
25	6	0	0.211722	-2.709386	1.760517
26	6	0	1.221628	-2.350732	0.888507

27	6	0	1.707703	-1.041324	0.832498
28	6	0	2.821631	-0.980402	-0.150549
29	6	0	2.935825	-2.241698	-0.758659
30	6	0	1.940831	-3.173980	-0.135021
31	6	0	-0.448907	0.611379	3.494137
32	6	0	-1.409311	-2.123128	3.597535
33	8	0	1.761840	-4.342651	-0.398596
34	6	0	3.890995	-2.507895	-1.721676
35	6	0	4.772505	-1.479861	-2.074291
36	6	0	4.694448	-0.239721	-1.442860
37	6	0	3.723240	0.025263	-0.468710
38	1	0	-3.831583	1.078984	1.908721
39	1	0	-6.183227	-0.784681	-2.094610
40	1	0	-7.397525	-0.492426	0.080619
41	1	0	-6.219639	0.425822	2.040384
42	1	0	-1.296247	1.635613	1.169182
43	1	0	-0.793408	0.328180	-3.607957
44	1	0	1.365431	1.724316	-3.554328
45	1	0	1.968947	0.257881	-2.772738
46	1	0	2.254940	1.834625	-2.027778
47	1	0	4.440330	4.554884	0.235428
48	1	0	3.336573	5.334771	1.526426
49	1	0	-0.158206	-3.731285	1.778522
50	1	0	-1.537666	0.666531	3.381603
51	1	0	-0.253353	0.340472	4.537458
52	1	0	-0.029011	1.605667	3.331031
53	1	0	-1.630700	-3.190561	3.537139
54	1	0	-1.122862	-1.891740	4.629048
55	1	0	-2.334474	-1.573485	3.388432
56	1	0	3.954610	-3.492178	-2.175864
57	1	0	5.534147	-1.652997	-2.827323
58	1	0	5.403005	0.538849	-1.707788
59	1	0	3.700824	0.993819	0.023581

Free Energy and Geometry O (Conformer 10 of 17):



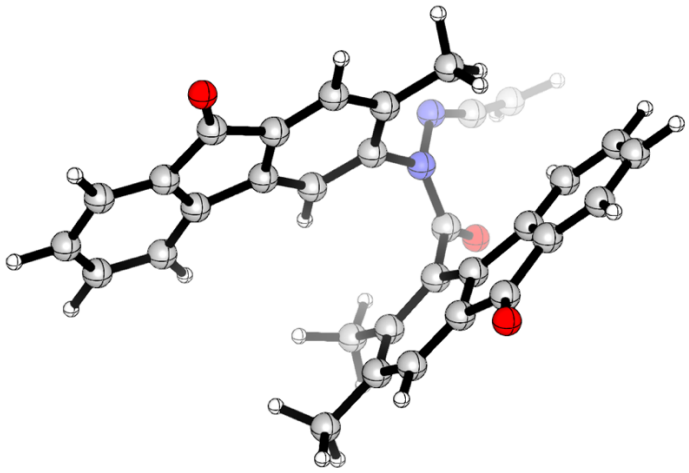
Sum of electronic and thermal free energies: -1566.775075 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-4.334283	0.673421	1.035432
2	6	0	-3.670875	0.508822	-0.170305
3	6	0	-4.349030	-0.015698	-1.282009
4	6	0	-5.681595	-0.381624	-1.219999
5	6	0	-6.351916	-0.215490	-0.004085
6	6	0	-5.683476	0.304703	1.104211
7	6	0	-3.402009	-0.087336	-2.440440
8	6	0	-2.098323	0.435658	-1.912285
9	6	0	-2.268250	0.789019	-0.565451
10	8	0	-3.634724	-0.480049	-3.562219
11	6	0	-1.201459	1.310585	0.137226
12	6	0	0.037388	1.435851	-0.510410
13	6	0	0.217264	1.101507	-1.858953
14	6	0	-0.892548	0.597239	-2.559490
15	6	0	1.529513	1.242580	-2.585484
16	7	0	1.136910	1.946810	0.263487
17	6	0	1.577715	1.361953	1.444278
18	7	0	1.541957	3.214291	-0.115340
19	6	0	2.507316	3.809817	0.379815
20	6	0	3.473862	4.623386	0.717565
21	8	0	2.316378	1.948296	2.210265
22	6	0	1.131309	-0.062319	1.630991
23	6	0	0.142113	-0.417454	2.566263
24	6	0	-0.322015	-1.746022	2.626325
25	6	0	0.211351	-2.708814	1.760984
26	6	0	1.221443	-2.350403	0.889088
27	6	0	1.707659	-1.041055	0.832951

28	6	0	2.821703	-0.980386	-0.149982
29	6	0	2.935809	-2.241773	-0.757920
30	6	0	1.940662	-3.173869	-0.134247
31	6	0	-0.449162	0.612277	3.494026
32	6	0	-1.409972	-2.122094	3.597587
33	8	0	1.761543	-4.342544	-0.397723
34	6	0	3.890993	-2.508198	-1.720861
35	6	0	4.772628	-1.480300	-2.073563
36	6	0	4.694664	-0.240073	-1.442292
37	6	0	3.723431	0.025143	-0.468232
38	1	0	-3.831742	1.080105	1.908239
39	1	0	-6.183179	-0.785118	-2.094490
40	1	0	-7.397641	-0.491856	0.080524
41	1	0	-6.219848	0.427146	2.039991
42	1	0	-1.296283	1.636143	1.168712
43	1	0	-0.793181	0.326759	-3.607876
44	1	0	1.969245	0.256584	-2.772179
45	1	0	1.365739	1.722517	-3.554723
46	1	0	2.255097	1.833792	-2.028155
47	1	0	4.441014	4.553921	0.232898
48	1	0	3.338205	5.333997	1.524597
49	1	0	-0.158696	-3.730669	1.779079
50	1	0	-1.537900	0.667531	3.381334
51	1	0	-0.253783	0.341496	4.537413
52	1	0	-0.029121	1.606490	3.330838
53	1	0	-1.631470	-3.189511	3.537288
54	1	0	-1.123757	-1.890588	4.629137
55	1	0	-2.335020	-1.572378	3.388160
56	1	0	3.954514	-3.492552	-2.174910
57	1	0	5.534297	-1.653603	-2.826529
58	1	0	5.403315	0.538391	-1.707281
59	1	0	3.701081	0.993768	0.023924

Free Energy and Geometry O (Conformer 11 of 17):



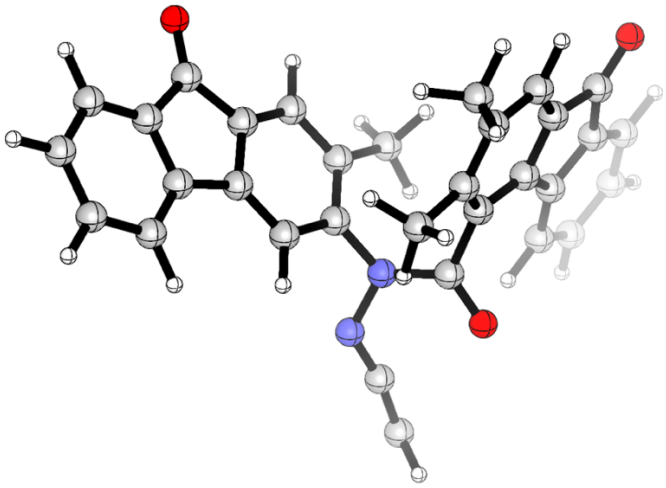
Sum of electronic and thermal free energies: -1566.775061 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	4.334735	0.671104	1.036545
2	6	0	3.671529	0.508013	-0.169513
3	6	0	4.349787	-0.015411	-1.281664
4	6	0	5.682258	-0.381711	-1.219801
5	6	0	6.352374	-0.217082	-0.003572
6	6	0	5.683829	0.302015	1.105177
7	6	0	3.402959	-0.085603	-2.440333
8	6	0	2.099266	0.437024	-1.911843
9	6	0	2.269028	0.788909	-0.564604
10	8	0	3.635800	-0.477141	-3.562499
11	6	0	1.202238	1.309993	0.138442
12	6	0	-0.036480	1.436172	-0.509244
13	6	0	-0.216235	1.103143	-1.858139
14	6	0	0.893607	0.599478	-2.559052
15	6	0	-1.528487	1.244756	-2.584567
16	7	0	-1.135862	1.946831	0.265050
17	6	0	-1.577285	1.360775	1.445008
18	7	0	-1.540886	3.214434	-0.112937
19	6	0	-2.504535	3.811139	0.384128
20	6	0	-3.469179	4.626306	0.723515
21	8	0	-2.316127	1.946528	2.211263
22	6	0	-1.131610	-0.063886	1.630402
23	6	0	-0.142668	-0.420411	2.565409
24	6	0	0.320496	-1.749357	2.624486
25	6	0	-0.213563	-2.711121	1.758417
26	6	0	-1.223346	-2.351317	0.886734
27	6	0	-1.708619	-1.041578	0.831596

28	6	0	-2.822699	-0.979360	-0.151201
29	6	0	-2.937846	-2.240240	-0.759986
30	6	0	-1.943325	-3.173519	-0.137081
31	6	0	0.449266	0.608205	3.493995
32	6	0	1.408122	-2.126955	3.595531
33	8	0	-1.765139	-4.342156	-0.401369
34	6	0	-3.893272	-2.505225	-1.723090
35	6	0	-4.774064	-1.476367	-2.075081
36	6	0	-4.695044	-0.236617	-1.443000
37	6	0	-3.723565	0.027142	-0.468796
38	1	0	3.832092	1.076872	1.909716
39	1	0	6.183928	-0.784348	-2.094637
40	1	0	7.398020	-0.493781	0.080933
41	1	0	6.220040	0.423280	2.041204
42	1	0	1.296991	1.634508	1.170264
43	1	0	0.794333	0.330132	-3.607735
44	1	0	-1.969469	0.259034	-2.769725
45	1	0	-1.364357	1.723063	-3.554542
46	1	0	-2.253194	1.837699	-2.027907
47	1	0	-4.437566	4.557854	0.241177
48	1	0	-3.330652	5.337279	1.529740
49	1	0	0.155697	-3.733272	1.775794
50	1	0	0.030124	1.602898	3.331361
51	1	0	0.253362	0.336910	4.537147
52	1	0	1.538077	0.662628	3.381619
53	1	0	1.628738	-3.194516	3.534561
54	1	0	2.333626	-1.577871	3.386466
55	1	0	1.122077	-1.895858	4.627220
56	1	0	-3.957608	-3.489212	-2.177819
57	1	0	-5.535889	-1.648532	-2.828151
58	1	0	-5.403030	0.542625	-1.707476
59	1	0	-3.700408	0.995442	0.023949

Free Energy and Geometry O (Conformer 12 of 17):



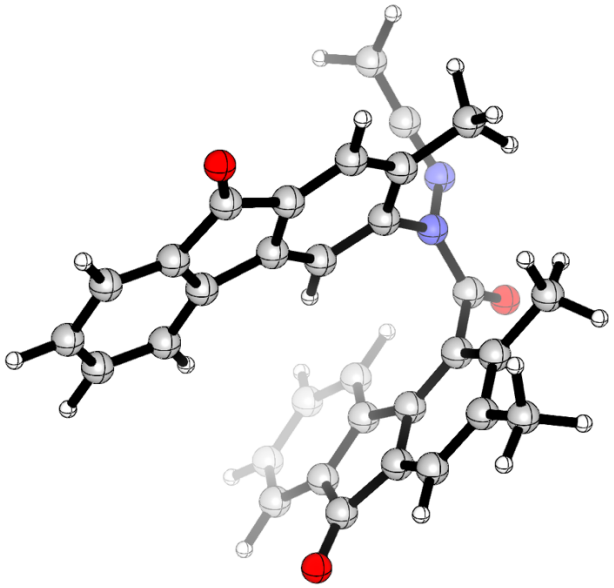
Sum of electronic and thermal free energies: -1566.776033 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	5.301588	0.958533	0.871591
2	6	0	4.522772	0.285753	-0.056566
3	6	0	5.098419	-0.689539	-0.886255
4	6	0	6.441755	-1.012002	-0.812359
5	6	0	7.228456	-0.334253	0.123901
6	6	0	6.661789	0.635754	0.951135
7	6	0	4.040197	-1.251047	-1.784820
8	6	0	2.783156	-0.522055	-1.411020
9	6	0	3.079089	0.390037	-0.384800
10	8	0	4.167317	-2.108845	-2.630629
11	6	0	2.074113	1.177005	0.136272
12	6	0	0.773882	1.035814	-0.379440
13	6	0	0.475768	0.169927	-1.438735
14	6	0	1.516768	-0.633874	-1.939255
15	6	0	-0.881591	0.088204	-2.081420
16	7	0	-0.245206	1.877060	0.187400
17	6	0	-1.266907	1.438609	1.017834
18	7	0	0.104908	3.222893	0.164455
19	6	0	-0.703022	4.131172	0.392006
20	6	0	-1.370861	5.243532	0.552571
21	8	0	-1.990330	2.226786	1.596305
22	6	0	-1.469160	-0.046864	1.129918
23	6	0	-0.585947	-0.859332	1.869424
24	6	0	-0.815612	-2.244773	1.970851
25	6	0	-1.940202	-2.804232	1.356511
26	6	0	-2.824014	-1.982809	0.684483
27	6	0	-2.618716	-0.602589	0.575107

28	6	0	-3.744718	-0.015579	-0.212135
29	6	0	-4.608086	-1.061348	-0.582086
30	6	0	-4.081691	-2.349614	-0.035466
31	6	0	0.589008	-0.264491	2.601734
32	6	0	0.135996	-3.117629	2.745977
33	8	0	-4.566209	-3.454332	-0.153384
34	6	0	-5.750138	-0.849636	-1.331702
35	6	0	-6.041551	0.458106	-1.730055
36	6	0	-5.195448	1.503337	-1.365346
37	6	0	-4.041888	1.284632	-0.600603
38	1	0	4.877316	1.717296	1.522184
39	1	0	6.862843	-1.769783	-1.466261
40	1	0	8.285879	-0.561539	0.209375
41	1	0	7.288021	1.152089	1.671940
42	1	0	2.253427	1.898276	0.927919
43	1	0	1.322197	-1.324014	-2.756416
44	1	0	-1.516604	0.932718	-1.806842
45	1	0	-0.773563	0.077953	-3.169565
46	1	0	-1.399781	-0.832300	-1.792742
47	1	0	-1.495698	5.673180	1.539478
48	1	0	-1.851550	5.716188	-0.296283
49	1	0	-2.128669	-3.873122	1.416643
50	1	0	1.538022	-0.628692	2.192828
51	1	0	0.596325	0.826728	2.558937
52	1	0	0.557848	-0.552626	3.657684
53	1	0	-0.150275	-4.168149	2.664269
54	1	0	1.162881	-3.013779	2.379804
55	1	0	0.144557	-2.851496	3.808998
56	1	0	-6.393144	-1.683514	-1.597079
57	1	0	-6.928499	0.662577	-2.320523
58	1	0	-5.435926	2.515751	-1.674555
59	1	0	-3.418971	2.125214	-0.314629

Free Energy and Geometry O (Conformer 13 of 17):



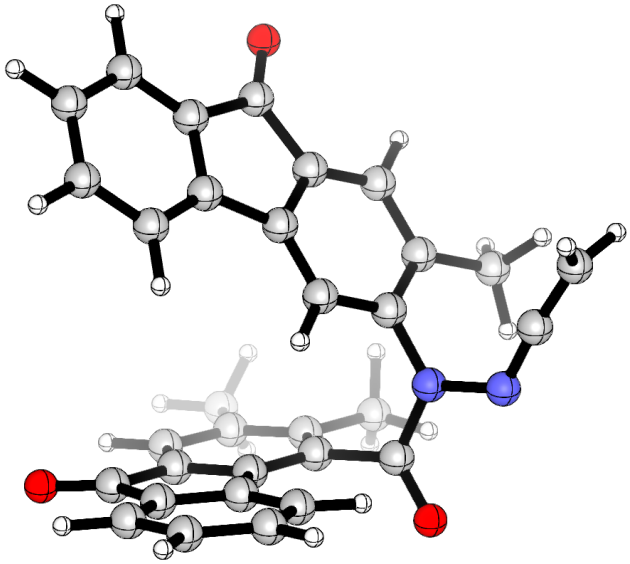
Sum of electronic and thermal free energies: -1566.779075 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	1.475351	2.912020	-0.983114
2	6	0	2.220947	1.835769	-0.529336
3	6	0	3.523082	2.029926	-0.042464
4	6	0	4.108031	3.283188	-0.004036
5	6	0	3.359957	4.369965	-0.467365
6	6	0	2.063129	4.182401	-0.946657
7	6	0	4.079429	0.710801	0.396828
8	6	0	2.987581	-0.284879	0.125544
9	6	0	1.892567	0.393005	-0.430646
10	8	0	5.171450	0.487319	0.870400
11	6	0	0.759340	-0.313037	-0.779291
12	6	0	0.728692	-1.691880	-0.523479
13	6	0	1.820302	-2.386076	0.018260
14	6	0	2.969964	-1.646418	0.343572
15	6	0	1.802018	-3.876531	0.234646
16	7	0	-0.467804	-2.410237	-0.858373
17	6	0	-1.696673	-2.208536	-0.243594
18	7	0	-0.485163	-3.287244	-1.934361
19	6	0	0.525843	-3.440777	-2.625756
20	6	0	1.528429	-3.690594	-3.426286
21	8	0	-2.705022	-2.781808	-0.597146
22	6	0	-1.694537	-1.191282	0.867740
23	6	0	-1.235432	-1.512669	2.157872

24	6	0	-1.243847	-0.538091	3.174942
25	6	0	-1.711148	0.750004	2.894022
26	6	0	-2.173698	1.040794	1.624870
27	6	0	-2.187644	0.081421	0.607512
28	6	0	-2.695254	0.714910	-0.642529
29	6	0	-2.969674	2.065771	-0.366549
30	6	0	-2.669271	2.340421	1.074632
31	6	0	-0.713185	-2.892665	2.460106
32	6	0	-0.741112	-0.876648	4.553860
33	8	0	-2.790522	3.392260	1.663967
34	6	0	-3.440345	2.934164	-1.333301
35	6	0	-3.641088	2.434180	-2.624396
36	6	0	-3.375657	1.095837	-2.906621
37	6	0	-2.903411	0.216708	-1.922105
38	1	0	0.461756	2.783429	-1.352555
39	1	0	5.116718	3.409624	0.377663
40	1	0	3.786839	5.367273	-0.451636
41	1	0	1.496169	5.039273	-1.296716
42	1	0	-0.102708	0.165861	-1.234976
43	1	0	3.835619	-2.144799	0.772735
44	1	0	2.295198	-4.131684	1.176453
45	1	0	0.786740	-4.277199	0.252640
46	1	0	2.347992	-4.383277	-0.568867
47	1	0	1.684192	-3.088701	-4.314550
48	1	0	2.220064	-4.497424	-3.209428
49	1	0	-1.706475	1.518958	3.662277
50	1	0	-0.958422	-3.605947	1.670285
51	1	0	0.377142	-2.876574	2.582669
52	1	0	-1.137107	-3.274581	3.393487
53	1	0	-0.740215	0.008515	5.193193
54	1	0	-1.369318	-1.637359	5.030831
55	1	0	0.278399	-1.275328	4.520550
56	1	0	-3.644417	3.971830	-1.086533
57	1	0	-4.008679	3.087397	-3.408813
58	1	0	-3.543118	0.719556	-3.910910
59	1	0	-2.728973	-0.825878	-2.167725

Free Energy and Geometry O (Conformer 14 of 17):



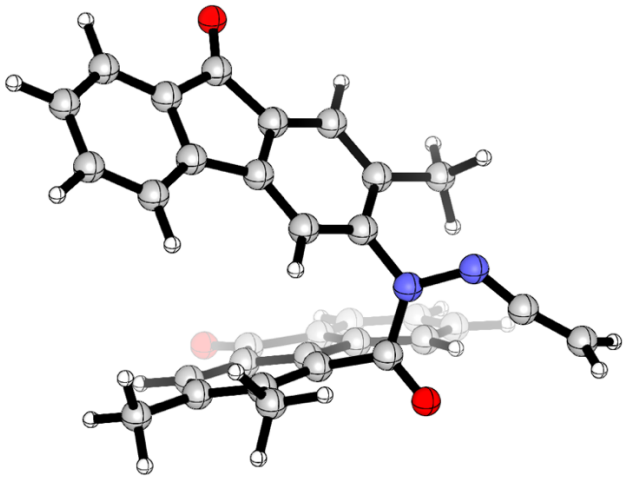
Sum of electronic and thermal free energies: -1566.779045 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-1.472296	2.913506	-0.981555
2	6	0	-2.218965	1.837998	-0.527770
3	6	0	-3.520694	2.033520	-0.040358
4	6	0	-4.104189	3.287445	-0.001401
5	6	0	-3.355038	4.373478	-0.464739
6	6	0	-2.058602	4.184550	-0.944558
7	6	0	-4.078361	0.714914	0.398831
8	6	0	-2.987767	-0.281942	0.126834
9	6	0	-1.892210	0.394835	-0.429596
10	8	0	-5.170480	0.492536	0.872701
11	6	0	-0.759924	-0.312412	-0.778893
12	6	0	-0.730758	-1.691348	-0.523484
13	6	0	-1.822920	-2.384443	0.018568
14	6	0	-2.971604	-1.643562	0.344519
15	6	0	-1.806310	-3.874976	0.234642
16	7	0	0.464768	-2.411012	-0.859178
17	6	0	1.694584	-2.209741	-0.246102
18	7	0	0.480518	-3.287495	-1.935598
19	6	0	-0.531159	-3.440133	-2.626183
20	6	0	-1.534578	-3.688810	-3.426031
21	8	0	2.702370	-2.782819	-0.601573
22	6	0	1.694149	-1.193373	0.866011
23	6	0	1.236038	-1.515500	2.156327
24	6	0	1.246149	-0.541775	3.174203

25	6	0	1.714104	0.746212	2.893911
26	6	0	2.175658	1.037719	1.624565
27	6	0	2.187976	0.079193	0.606382
28	6	0	2.694904	0.713399	-0.643589
29	6	0	2.970478	2.063847	-0.366711
30	6	0	2.671593	2.337475	1.074975
31	6	0	0.713292	-2.895406	2.458100
32	6	0	0.744492	-0.881122	4.553319
33	8	0	2.794200	3.388702	1.665124
34	6	0	3.440806	2.932771	-1.333153
35	6	0	3.640016	2.433778	-2.624866
36	6	0	3.373492	1.095841	-2.907982
37	6	0	2.901606	0.216165	-1.923781
38	1	0	-0.458983	2.783837	-1.351400
39	1	0	-5.112583	3.414953	0.380713
40	1	0	-3.780771	5.371271	-0.448605
41	1	0	-1.490797	5.040863	-1.294615
42	1	0	0.102442	0.165665	-1.234831
43	1	0	-3.837652	-2.141051	0.773921
44	1	0	-0.791572	-4.277017	0.251239
45	1	0	-2.298591	-4.129621	1.177066
46	1	0	-2.354120	-4.380782	-0.568214
47	1	0	-2.226798	-4.495095	-3.209140
48	1	0	-1.690395	-3.086264	-4.313844
49	1	0	1.710726	1.514531	3.662810
50	1	0	1.138953	-3.278696	3.390127
51	1	0	-0.376733	-2.878559	2.583158
52	1	0	0.956163	-3.608011	1.666954
53	1	0	0.745278	0.003422	5.193509
54	1	0	1.372293	-1.643030	5.028895
55	1	0	-0.275526	-1.278577	4.520675
56	1	0	3.645782	3.970091	-1.085681
57	1	0	4.007268	3.087445	-3.409067
58	1	0	3.539799	0.720297	-3.912739
59	1	0	2.726329	-0.826110	-2.170102

Free Energy and Geometry O (Conformer 15 of 17):



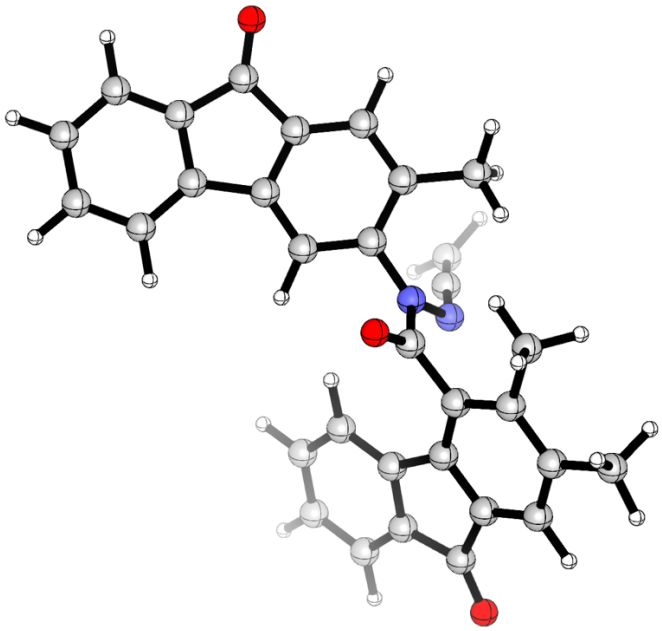
Sum of electronic and thermal free energies: -1566.775764 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-4.210509	-0.072980	1.198243
2	6	0	-3.606755	0.483837	0.082476
3	6	0	-4.329757	0.633672	-1.111218
4	6	0	-5.651335	0.240016	-1.218578
5	6	0	-6.262911	-0.320352	-0.092404
6	6	0	-5.548729	-0.472757	1.096048
7	6	0	-3.437213	1.251281	-2.144791
8	6	0	-2.120029	1.450115	-1.454957
9	6	0	-2.230569	0.992788	-0.135367
10	8	0	-3.717191	1.532189	-3.289254
11	6	0	-1.142876	1.079846	0.710566
12	6	0	0.062153	1.589022	0.206411
13	6	0	0.180852	2.073375	-1.106261
14	6	0	-0.947442	1.994361	-1.937445
15	6	0	1.449946	2.691403	-1.627802
16	7	0	1.197172	1.637910	1.082496
17	6	0	1.644621	0.566136	1.849123
18	7	0	1.673235	2.921370	1.298117
19	6	0	2.730555	3.169002	1.890724
20	6	0	3.800230	3.673156	2.448676
21	8	0	2.438699	0.723089	2.755056
22	6	0	1.136681	-0.783900	1.421188
23	6	0	0.192391	-1.493229	2.187804
24	6	0	-0.318217	-2.718193	1.717031
25	6	0	0.128140	-3.232367	0.493644
26	6	0	1.100969	-2.551509	-0.211649
27	6	0	1.632234	-1.343375	0.250948

28	6	0	2.708733	-0.905392	-0.677319
29	6	0	2.760391	-1.813646	-1.747866
30	6	0	1.750897	-2.896454	-1.515809
31	6	0	-0.300145	-0.948687	3.504285
32	6	0	-1.352681	-3.464171	2.518271
33	8	0	1.519097	-3.851475	-2.223950
34	6	0	3.682534	-1.692935	-2.770356
35	6	0	4.593511	-0.632874	-2.712255
36	6	0	4.575826	0.249080	-1.633498
37	6	0	3.640206	0.120167	-0.598019
38	1	0	-3.668729	-0.197498	2.131464
39	1	0	-6.189363	0.365801	-2.153369
40	1	0	-7.298567	-0.639914	-0.140967
41	1	0	-6.039663	-0.910102	1.959839
42	1	0	-1.206669	0.781120	1.751500
43	1	0	-0.891621	2.352259	-2.962135
44	1	0	1.462833	2.659155	-2.719621
45	1	0	1.526081	3.737063	-1.312823
46	1	0	2.335020	2.172043	-1.256505
47	1	0	3.811712	3.905754	3.507151
48	1	0	4.705164	3.810182	1.867729
49	1	0	-0.274284	-4.165688	0.108369
50	1	0	0.141060	0.020046	3.744650
51	1	0	-1.391539	-0.847183	3.509745
52	1	0	-0.044668	-1.635704	4.318456
53	1	0	-1.615862	-4.404916	2.030664
54	1	0	-0.989455	-3.692220	3.526126
55	1	0	-2.269576	-2.874513	2.632085
56	1	0	3.698443	-2.412573	-3.583375
57	1	0	5.330697	-0.506829	-3.498189
58	1	0	5.307089	1.050064	-1.587212
59	1	0	3.673980	0.801668	0.248244

Free Energy and Geometry O (Conformer 16 of 17):



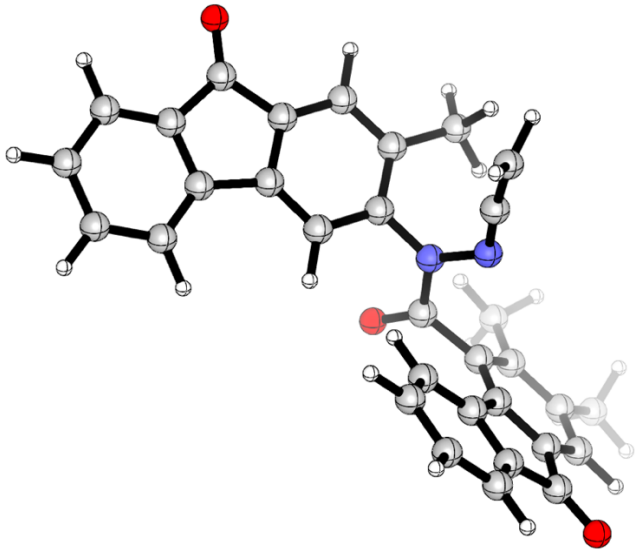
Sum of electronic and thermal free energies: -1566.779056 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-4.279358	2.011144	-1.482373
2	6	0	-4.364142	0.834060	-0.756081
3	6	0	-5.618654	0.293357	-0.432689
4	6	0	-6.799144	0.902899	-0.818038
5	6	0	-6.714990	2.091392	-1.549951
6	6	0	-5.471189	2.632954	-1.874708
7	6	0	-5.417351	-0.969934	0.345174
8	6	0	-3.928958	-1.128815	0.455296
9	6	0	-3.311671	-0.053329	-0.200461
10	8	0	-6.267509	-1.707922	0.792092
11	6	0	-1.932878	0.025618	-0.233662
12	6	0	-1.196470	-0.989551	0.392600
13	6	0	-1.799155	-2.084513	1.028528
14	6	0	-3.201531	-2.134049	1.057307
15	6	0	-0.988322	-3.189802	1.651340
16	7	0	0.233908	-0.897069	0.386044
17	6	0	0.948424	-0.912392	-0.800539
18	7	0	0.949349	-0.727237	1.559003
19	6	0	0.365215	-0.530701	2.629034
20	6	0	-0.136861	-0.327125	3.817825
21	8	0	0.376719	-1.011753	-1.868579
22	6	0	2.448148	-0.855301	-0.698938

23	6	0	3.176876	-2.000116	-1.081984
24	6	0	4.584992	-1.967664	-1.112058
25	6	0	5.255670	-0.790769	-0.768397
26	6	0	4.524247	0.319636	-0.395394
27	6	0	3.125394	0.308974	-0.350105
28	6	0	2.657902	1.657259	0.085480
29	6	0	3.786745	2.466884	0.297892
30	6	0	5.018996	1.670207	0.008266
31	6	0	2.476492	-3.284081	-1.451567
32	6	0	5.366239	-3.190856	-1.515351
33	8	0	6.170556	2.041095	0.084693
34	6	0	3.689283	3.782483	0.709850
35	6	0	2.413017	4.314387	0.917317
36	6	0	1.285674	3.522692	0.708947
37	6	0	1.393355	2.189646	0.292750
38	1	0	-3.320052	2.446101	-1.746026
39	1	0	-7.756896	0.463284	-0.556138
40	1	0	-7.620502	2.596712	-1.869047
41	1	0	-5.424841	3.555656	-2.444625
42	1	0	-1.414505	0.830027	-0.745907
43	1	0	-3.709408	-2.966514	1.537505
44	1	0	-0.015492	-3.297763	1.164568
45	1	0	-0.808747	-2.997961	2.715175
46	1	0	-1.524473	-4.138380	1.574071
47	1	0	-0.341276	0.681025	4.160839
48	1	0	-0.362842	-1.161646	4.472890
49	1	0	6.341537	-0.745053	-0.791742
50	1	0	2.611010	-3.503119	-2.516914
51	1	0	2.899854	-4.125213	-0.893901
52	1	0	1.403960	-3.251037	-1.258722
53	1	0	6.434994	-2.970324	-1.554245
54	1	0	5.216236	-4.012250	-0.805670
55	1	0	5.056848	-3.556828	-2.500110
56	1	0	4.585847	4.375400	0.864352
57	1	0	2.297569	5.343519	1.240799
58	1	0	0.299181	3.945108	0.873201
59	1	0	0.495094	1.600461	0.146803

Free Energy and Geometry O (Conformer 17 of 17):



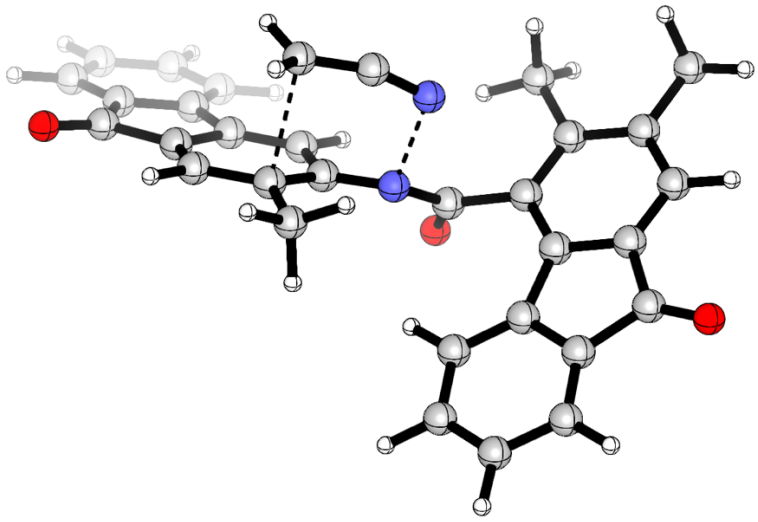
Sum of electronic and thermal free energies: -1566.779016 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	4.279580	2.010341	-1.483297
2	6	0	4.364228	0.833587	-0.756454
3	6	0	5.618678	0.293000	-0.432634
4	6	0	6.799242	0.902335	-0.818093
5	6	0	6.715225	2.090493	-1.550567
6	6	0	5.471485	2.631940	-1.875748
7	6	0	5.417234	-0.969906	0.345814
8	6	0	3.928824	-1.128688	0.455813
9	6	0	3.311656	-0.053509	-0.200560
10	8	0	6.267311	-1.707720	0.793179
11	6	0	1.932870	0.025466	-0.233971
12	6	0	1.196358	-0.989367	0.392713
13	6	0	1.798918	-2.084016	1.029295
14	6	0	3.201292	-2.133588	1.058259
15	6	0	0.987966	-3.188909	1.652665
16	7	0	-0.234008	-0.896778	0.386028
17	6	0	-0.948454	-0.912650	-0.800592
18	7	0	-0.949469	-0.726425	1.558916
19	6	0	-0.365315	-0.529188	2.628813
20	6	0	0.136776	-0.325153	3.817527
21	8	0	-0.376700	-1.012677	-1.868546
22	6	0	-2.448172	-0.855467	-0.699062
23	6	0	-3.176962	-2.000261	-1.082055
24	6	0	-4.585097	-1.967797	-1.111902
25	6	0	-5.255702	-0.790885	-0.768167

26	6	0	-4.524202	0.319536	-0.395350
27	6	0	-3.125348	0.308845	-0.350221
28	6	0	-2.657765	1.657146	0.085205
29	6	0	-3.786565	2.466798	0.297737
30	6	0	-5.018871	1.670136	0.008301
31	6	0	-2.476665	-3.284198	-1.451901
32	6	0	-5.366425	-3.191008	-1.514976
33	8	0	-6.170416	2.041044	0.084891
34	6	0	-3.689032	3.782411	0.709634
35	6	0	-2.412728	4.314310	0.916895
36	6	0	-1.285423	3.522601	0.708365
37	6	0	-1.393176	2.189538	0.292237
38	1	0	3.320324	2.445206	-1.747284
39	1	0	7.756943	0.462815	-0.555847
40	1	0	7.620796	2.595645	-1.869759
41	1	0	5.425240	3.554382	-2.446092
42	1	0	1.414568	0.829651	-0.746640
43	1	0	3.709085	-2.965808	1.538969
44	1	0	1.524000	-4.137589	1.575826
45	1	0	0.808454	-2.996527	2.716416
46	1	0	0.015104	-3.296979	1.165985
47	1	0	0.362758	-1.159445	4.472881
48	1	0	0.341208	0.683118	4.160166
49	1	0	-6.341572	-0.745141	-0.791358
50	1	0	-2.900466	-4.125537	-0.894892
51	1	0	-2.610723	-3.502631	-2.517441
52	1	0	-1.404212	-3.251488	-1.258588
53	1	0	-6.435114	-2.970269	-1.554479
54	1	0	-5.216940	-4.012057	-0.804774
55	1	0	-5.056643	-3.557598	-2.499373
56	1	0	-4.585572	4.375338	0.864234
57	1	0	-2.297220	5.343451	1.240326
58	1	0	-0.298899	3.945012	0.872442
59	1	0	-0.494931	1.600357	0.146135

Free Energy and Geometry S-TS2:



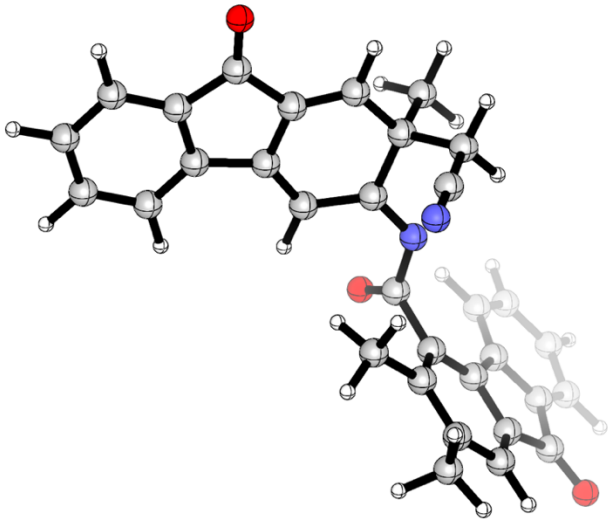
Sum of electronic and thermal free energies: -1566.735261 a.u.

Number of imaginary frequencies: 1

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-4.867501	1.791509	-1.392086
2	6	0	-4.659176	0.620776	-0.677096
3	6	0	-5.749937	-0.176793	-0.296476
4	6	0	-7.053875	0.168251	-0.612869
5	6	0	-7.263549	1.347315	-1.330611
6	6	0	-6.181858	2.144274	-1.712944
7	6	0	-5.250481	-1.369156	0.453210
8	6	0	-3.758943	-1.214127	0.485196
9	6	0	-3.409191	-0.014364	-0.195663
10	8	0	-5.902445	-2.267851	0.939000
11	6	0	-2.100959	0.363985	-0.311838
12	6	0	-1.088169	-0.492410	0.224198
13	6	0	-1.446068	-1.650028	0.983760
14	6	0	-2.821254	-2.021504	1.058943
15	6	0	-0.380832	-2.632642	1.401159
16	7	0	0.225696	-0.163870	0.252167
17	6	0	0.831490	0.648323	-0.696210
18	7	0	0.577619	0.712900	1.940475
19	6	0	-0.283198	0.280936	2.652241
20	6	0	-1.374131	-0.396113	3.063358
21	8	0	0.382290	0.810574	-1.817477
22	6	0	2.193650	1.162007	-0.315409
23	6	0	2.383884	2.506263	0.050146
24	6	0	3.670166	2.978642	0.370706
25	6	0	4.760650	2.102972	0.321525

26	6	0	4.554492	0.787581	-0.045159
27	6	0	3.281759	0.302007	-0.370322
28	6	0	3.400138	-1.139027	-0.734390
29	6	0	4.747003	-1.515649	-0.596274
30	6	0	5.544051	-0.326366	-0.157954
31	6	0	1.206270	3.439308	0.157605
32	6	0	3.870187	4.415017	0.778554
33	8	0	6.736574	-0.279521	0.057825
34	6	0	5.186879	-2.798494	-0.864249
35	6	0	4.245861	-3.740724	-1.290672
36	6	0	2.910233	-3.373613	-1.445127
37	6	0	2.470090	-2.071610	-1.173222
38	1	0	-4.037490	2.420336	-1.699367
39	1	0	-7.880297	-0.466342	-0.307482
40	1	0	-8.271532	1.648860	-1.595540
41	1	0	-6.365076	3.056389	-2.272135
42	1	0	-1.806607	1.264217	-0.839542
43	1	0	-3.110991	-2.931004	1.579420
44	1	0	-0.769071	-3.326328	2.150960
45	1	0	-0.064492	-3.218280	0.530580
46	1	0	0.506844	-2.132315	1.792020
47	1	0	-1.259941	-1.291177	3.666166
48	1	0	-2.334608	0.110492	3.071430
49	1	0	5.760018	2.449989	0.571769
50	1	0	0.289357	2.988556	-0.226657
51	1	0	1.033574	3.712843	1.204879
52	1	0	1.382698	4.365699	-0.398098
53	1	0	4.915360	4.604004	1.032635
54	1	0	3.587901	5.102262	-0.026876
55	1	0	3.256207	4.671487	1.648871
56	1	0	6.235873	-3.054070	-0.747169
57	1	0	4.554652	-4.757571	-1.509727
58	1	0	2.191206	-4.111511	-1.788093
59	1	0	1.425777	-1.814644	-1.313508

Free Energy and Geometry 39* (Conformer 1 of 21):



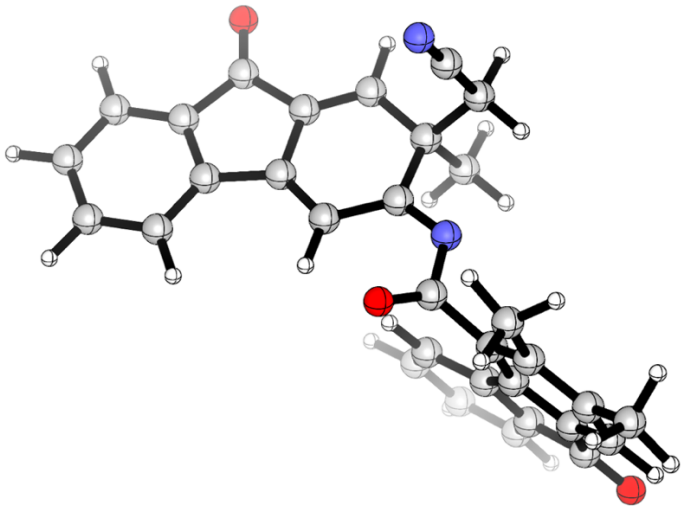
Sum of electronic and thermal free energies: -1566.812780 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	4.292886	0.212413	-2.679813
2	6	0	4.349748	-0.084620	-1.320474
3	6	0	5.586705	-0.134892	-0.657399
4	6	0	6.780942	0.106060	-1.323317
5	6	0	6.721355	0.402223	-2.682661
6	6	0	5.490042	0.453841	-3.349658
7	6	0	5.379650	-0.471551	0.780355
8	6	0	3.898606	-0.625104	0.934190
9	6	0	3.269130	-0.375297	-0.365003
10	6	0	1.932820	-0.417772	-0.535787
11	6	0	1.076181	-0.678662	0.617023
12	6	0	1.703927	-1.137909	1.943783
13	6	0	3.195710	-0.956499	2.016714
14	8	0	6.223157	-0.601577	1.640488
15	6	0	1.406912	-2.650126	2.080348
16	6	0	1.026313	-0.408196	3.125964
17	6	0	1.251366	1.039765	3.068559
18	7	0	1.441911	2.177872	3.000905
19	7	0	-0.205767	-0.568696	0.620756
20	6	0	-0.961691	-0.365136	-0.533122
21	8	0	-0.856166	-1.048019	-1.534757
22	6	0	-2.046776	0.666209	-0.381322
23	6	0	-3.381231	0.272376	-0.408965
24	6	0	-4.374857	1.244729	-0.235887
25	6	0	-4.073899	2.579018	-0.049712

26	6	0	-2.735956	2.985933	-0.035873
27	6	0	-1.720162	2.026757	-0.206508
28	6	0	-0.279200	2.472726	-0.204972
29	6	0	-2.393518	4.439737	0.165709
30	6	0	-5.716169	0.588856	-0.264306
31	6	0	-5.435041	-0.866387	-0.455817
32	6	0	-4.045126	-1.060930	-0.544815
33	6	0	-3.549802	-2.346976	-0.716514
34	6	0	-4.461096	-3.408736	-0.791459
35	6	0	-5.836181	-3.202773	-0.703963
36	6	0	-6.338465	-1.909576	-0.533788
37	8	0	-6.799414	1.122120	-0.150688
38	1	0	3.344950	0.256064	-3.206873
39	1	0	7.725214	0.061997	-0.789733
40	1	0	7.634780	0.595983	-3.235212
41	1	0	5.470161	0.687075	-4.409300
42	1	0	1.467460	-0.236490	-1.498471
43	1	0	3.687673	-1.154043	2.968018
44	1	0	1.856070	-3.201305	1.250159
45	1	0	1.818009	-3.032947	3.018899
46	1	0	0.324665	-2.807185	2.066602
47	1	0	-0.050097	-0.593050	3.093847
48	1	0	1.420579	-0.789313	4.073011
49	1	0	-4.873877	3.302353	0.087151
50	1	0	0.094460	2.602961	0.817703
51	1	0	0.374519	1.757356	-0.708499
52	1	0	-0.168334	3.430516	-0.719520
53	1	0	-1.682793	4.573177	0.987705
54	1	0	-1.935248	4.871421	-0.731355
55	1	0	-3.291550	5.017803	0.393776
56	1	0	-2.488196	-2.543387	-0.803447
57	1	0	-4.081532	-4.417020	-0.925754
58	1	0	-6.514636	-4.047026	-0.768916
59	1	0	-7.404643	-1.716350	-0.460823

Free Energy and Geometry 39* (Conformer 2 of 21):



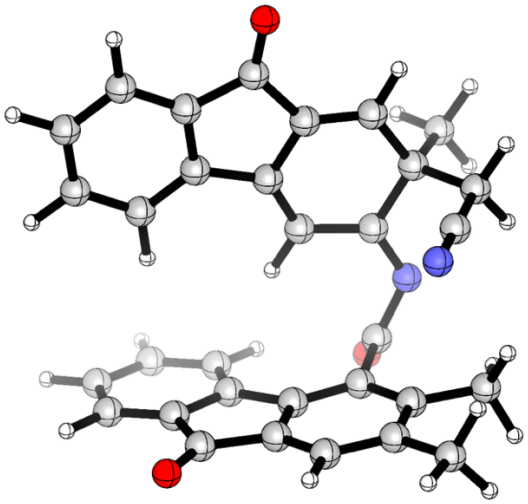
Sum of electronic and thermal free energies: -1566.810918 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	4.025435	-0.709783	-2.535917
2	6	0	4.036804	-0.380377	-1.182843
3	6	0	5.234952	-0.427519	-0.451556
4	6	0	6.434889	-0.799342	-1.042404
5	6	0	6.420682	-1.129277	-2.395435
6	6	0	5.228445	-1.083787	-3.130240
7	6	0	4.981545	-0.032884	0.964147
8	6	0	3.514560	0.257055	1.029466
9	6	0	2.940495	0.048093	-0.300492
10	6	0	1.636154	0.268581	-0.570283
11	6	0	0.763537	0.747390	0.493448
12	6	0	1.282749	0.777282	1.940648
13	6	0	2.772327	0.624858	2.073733
14	8	0	5.782802	0.031937	1.870661
15	6	0	0.632965	-0.424792	2.670379
16	6	0	0.811102	2.073506	2.636757
17	6	0	1.378906	3.267886	2.002247
18	7	0	1.837510	4.195062	1.487063
19	7	0	-0.480206	1.074361	0.368567
20	6	0	-1.132499	1.131924	-0.868670
21	8	0	-0.619204	1.487951	-1.912606
22	6	0	-2.610101	0.859885	-0.761170
23	6	0	-3.090404	-0.376895	-0.336923
24	6	0	-4.469995	-0.557862	-0.180194
25	6	0	-5.377423	0.443215	-0.462878
26	6	0	-4.911039	1.678355	-0.920845

27	6	0	-3.525067	1.893409	-1.062591
28	6	0	-3.056553	3.252756	-1.520286
29	6	0	-5.891559	2.775279	-1.246269
30	6	0	-4.732622	-1.934341	0.335696
31	6	0	-3.386193	-2.578958	0.430046
32	6	0	-2.410425	-1.663576	-0.001923
33	6	0	-1.090245	-2.079942	-0.097026
34	6	0	-0.766412	-3.387142	0.289967
35	6	0	-1.738309	-4.272773	0.749783
36	6	0	-3.076321	-3.870912	0.810364
37	8	0	-5.805362	-2.425738	0.614165
38	1	0	3.108539	-0.675919	-3.116003
39	1	0	7.348978	-0.827565	-0.457728
40	1	0	7.340126	-1.424287	-2.890254
41	1	0	5.244182	-1.344280	-4.183567
42	1	0	1.234048	0.168509	-1.571248
43	1	0	3.214644	0.762876	3.059193
44	1	0	0.928895	-1.363602	2.193547
45	1	0	0.948703	-0.448371	3.717238
46	1	0	-0.455221	-0.330410	2.613421
47	1	0	-0.278543	2.132448	2.579669
48	1	0	1.107005	2.057713	3.690445
49	1	0	-6.441969	0.266431	-0.331709
50	1	0	-1.986512	3.399336	-1.383096
51	1	0	-3.273380	3.392076	-2.585917
52	1	0	-3.585412	4.042446	-0.979112
53	1	0	-5.787686	3.622117	-0.558478
54	1	0	-5.736729	3.162973	-2.258536
55	1	0	-6.917499	2.408111	-1.174433
56	1	0	-0.310153	-1.433304	-0.482018
57	1	0	0.266350	-3.715372	0.220083
58	1	0	-1.457392	-5.278899	1.042782
59	1	0	-3.860284	-4.548070	1.136128

Free Energy and Geometry 39* (Conformer 3 of 21):



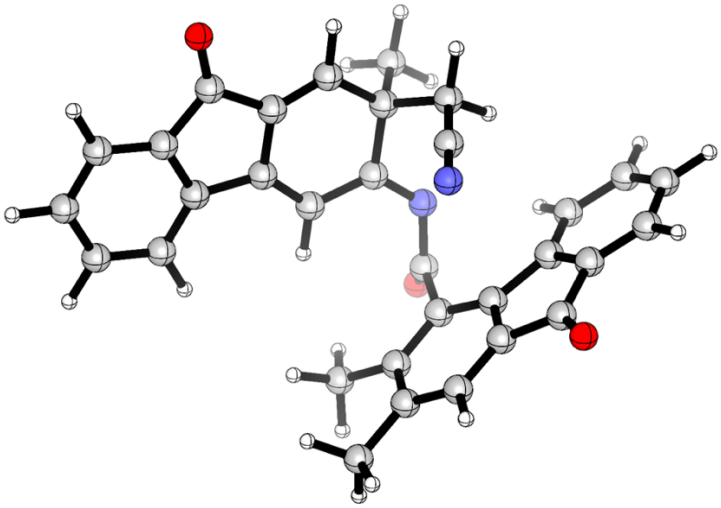
Sum of electronic and thermal free energies: -1566.814160 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	2.530237	2.071234	-0.027214
2	6	0	2.787820	0.711691	0.131312
3	6	0	3.937592	0.272954	0.806226
4	6	0	4.856615	1.173386	1.329849
5	6	0	4.602058	2.533098	1.167773
6	6	0	3.451391	2.973487	0.498459
7	6	0	3.961572	-1.219408	0.853130
8	6	0	2.710172	-1.652462	0.149877
9	6	0	2.000299	-0.451044	-0.295062
10	6	0	0.834216	-0.516083	-0.958693
11	6	0	0.203084	-1.812291	-1.182110
12	6	0	0.982321	-3.102588	-0.880644
13	6	0	2.255024	-2.880357	-0.100254
14	8	0	4.807768	-1.931345	1.348367
15	6	0	1.352077	-3.770028	-2.222397
16	6	0	0.055494	-4.064199	-0.098120
17	6	0	-0.420230	-3.461299	1.152290
18	7	0	-0.806773	-2.962445	2.121013
19	7	0	-0.992057	-1.950189	-1.623314
20	6	0	-1.832295	-0.851877	-1.840526
21	8	0	-2.082077	-0.427339	-2.948630
22	6	0	-2.422404	-0.292941	-0.571009
23	6	0	-2.167905	1.031667	-0.210694
24	6	0	-2.549152	1.461007	1.068942
25	6	0	-3.207061	0.638963	1.960548
26	6	0	-3.527615	-0.667031	1.580473

27	6	0	-3.136859	-1.134061	0.312143
28	6	0	-3.541737	-2.531581	-0.087184
29	6	0	-4.248723	-1.578460	2.536802
30	6	0	-2.068371	2.855257	1.290913
31	6	0	-1.373911	3.234916	0.023442
32	6	0	-1.462838	2.168149	-0.889487
33	6	0	-0.936562	2.331533	-2.167104
34	6	0	-0.296842	3.539193	-2.481311
35	6	0	-0.193007	4.576039	-1.556559
36	6	0	-0.750479	4.429940	-0.282324
37	8	0	-2.205587	3.534085	2.285908
38	1	0	1.637360	2.420776	-0.540836
39	1	0	5.740163	0.817538	1.850461
40	1	0	5.297863	3.264107	1.566273
41	1	0	3.273289	4.038905	0.391404
42	1	0	0.326224	0.379054	-1.299309
43	1	0	2.811004	-3.761229	0.217905
44	1	0	2.007290	-3.115654	-2.803188
45	1	0	1.870330	-4.717194	-2.046845
46	1	0	0.439988	-3.956131	-2.796235
47	1	0	-0.817674	-4.298568	-0.714567
48	1	0	0.582355	-4.996032	0.129478
49	1	0	-3.468624	1.009677	2.948336
50	1	0	-3.273049	-2.771184	-1.115579
51	1	0	-3.076788	-3.273159	0.571911
52	1	0	-4.626097	-2.646749	0.015855
53	1	0	-5.203280	-1.923731	2.124863
54	1	0	-3.643630	-2.466325	2.752126
55	1	0	-4.451278	-1.066464	3.479812
56	1	0	-1.020079	1.555226	-2.918327
57	1	0	0.120107	3.667071	-3.475434
58	1	0	0.306725	5.499042	-1.831627
59	1	0	-0.705130	5.225447	0.455569

Free Energy and Geometry 39* (Conformer 4 of 21):



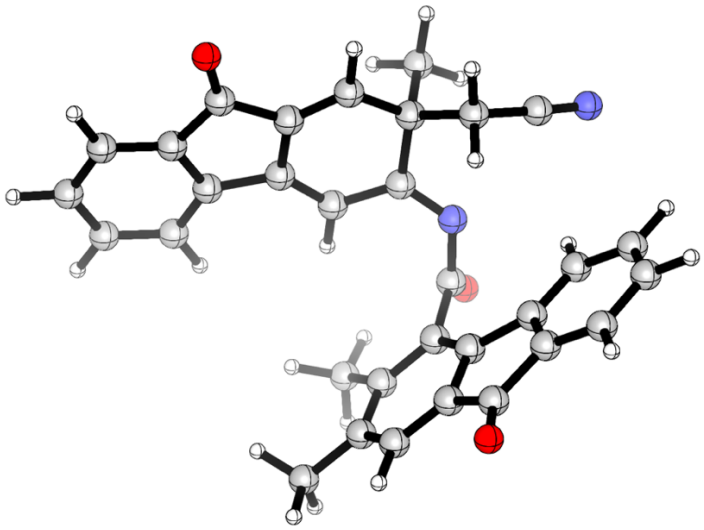
Sum of electronic and thermal free energies: -1566.811446 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-4.323717	1.627099	0.464616
2	6	0	-3.932521	0.355758	0.051781
3	6	0	-4.770530	-0.407786	-0.776931
4	6	0	-5.999618	0.071044	-1.210976
5	6	0	-6.387177	1.342982	-0.798204
6	6	0	-5.556480	2.108796	0.030791
7	6	0	-4.136006	-1.725406	-1.068300
8	6	0	-2.829552	-1.698150	-0.339207
9	6	0	-2.706672	-0.404786	0.342149
10	6	0	-1.616881	-0.085362	1.063534
11	6	0	-0.510971	-1.038208	1.155568
12	6	0	-0.667739	-2.461233	0.593711
13	6	0	-1.900099	-2.648792	-0.250613
14	8	0	-4.581155	-2.628867	-1.742328
15	6	0	-0.746943	-3.447454	1.778434
16	6	0	0.592725	-2.806251	-0.237602
17	6	0	0.822469	-1.833402	-1.311563
18	7	0	0.994225	-1.043703	-2.138221
19	7	0	0.618746	-0.769639	1.690603
20	6	0	0.982557	0.490732	2.165340
21	8	0	0.935995	0.790769	3.339911
22	6	0	1.505751	1.382613	1.069727
23	6	0	2.501575	0.925182	0.204273
24	6	0	2.836984	1.696094	-0.912948
25	6	0	2.239816	2.913130	-1.173237
26	6	0	1.286604	3.410846	-0.282375

27	6	0	0.917920	2.648628	0.845506
28	6	0	-0.133276	3.219773	1.765681
29	6	0	0.647458	4.750701	-0.538716
30	6	0	3.868704	0.977219	-1.718931
31	6	0	4.175933	-0.261618	-0.942382
32	6	0	3.384410	-0.283807	0.218424
33	6	0	3.579300	-1.296325	1.149636
34	6	0	4.528602	-2.289231	0.871797
35	6	0	5.279125	-2.275497	-0.302195
36	6	0	5.111830	-1.238727	-1.224489
37	8	0	4.360536	1.331731	-2.768398
38	1	0	-3.690880	2.229580	1.109112
39	1	0	-6.629993	-0.537728	-1.851570
40	1	0	-7.341052	1.749318	-1.117944
41	1	0	-5.881732	3.096698	0.340580
42	1	0	-1.517443	0.869644	1.571450
43	1	0	-2.030027	-3.606809	-0.751938
44	1	0	-1.627782	-3.236896	2.390384
45	1	0	-0.812751	-4.476309	1.412252
46	1	0	0.148230	-3.338857	2.397253
47	1	0	1.470494	-2.796196	0.415755
48	1	0	0.493152	-3.805755	-0.672211
49	1	0	2.519250	3.477383	-2.059333
50	1	0	-0.319351	2.591750	2.634865
51	1	0	0.182008	4.202019	2.133652
52	1	0	-1.074862	3.375664	1.225208
53	1	0	-0.440605	4.664896	-0.632733
54	1	0	0.844507	5.451471	0.280100
55	1	0	1.032969	5.190750	-1.460628
56	1	0	3.013975	-1.336673	2.073420
57	1	0	4.683306	-3.084873	1.594279
58	1	0	6.003495	-3.061160	-0.490061
59	1	0	5.699808	-1.184945	-2.135841

Free Energy and Geometry 39* (Conformer 5 of 21):



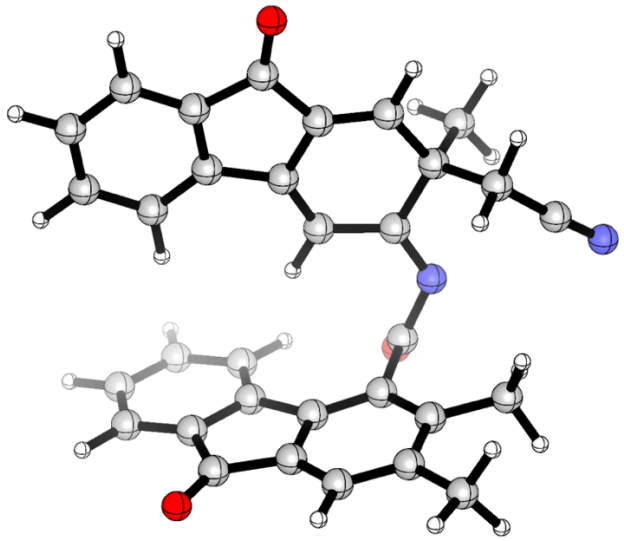
Sum of electronic and thermal free energies: -1566.808632 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-4.316852	1.402729	0.621194
2	6	0	-3.840359	0.263105	-0.021698
3	6	0	-4.564803	-0.306093	-1.081575
4	6	0	-5.761892	0.241749	-1.523547
5	6	0	-6.234379	1.382860	-0.880834
6	6	0	-5.518059	1.953070	0.179920
7	6	0	-3.858442	-1.516989	-1.590711
8	6	0	-2.637706	-1.643722	-0.735541
9	6	0	-2.618125	-0.523515	0.212784
10	6	0	-1.588519	-0.336477	1.057876
11	6	0	-0.437088	-1.244197	0.976068
12	6	0	-0.632571	-2.616959	0.325614
13	6	0	-1.712818	-2.604195	-0.729272
14	8	0	-4.200686	-2.248434	-2.494551
15	6	0	-1.124466	-3.585582	1.433486
16	6	0	0.691110	-3.127429	-0.292767
17	6	0	1.650251	-3.648343	0.686968
18	7	0	2.408090	-4.101351	1.433304
19	7	0	0.720890	-0.972520	1.439089
20	6	0	1.040251	0.229871	2.077136
21	8	0	1.100201	0.321028	3.284682
22	6	0	1.363638	1.356692	1.130440
23	6	0	2.300551	1.191323	0.107682
24	6	0	2.479379	2.222247	-0.821791
25	6	0	1.775434	3.407471	-0.753752
26	6	0	0.869351	3.604256	0.290275

27	6	0	0.665922	2.582854	1.241091
28	6	0	-0.330268	2.848221	2.343569
29	6	0	0.113577	4.903536	0.391547
30	6	0	3.498395	1.808693	-1.833583
31	6	0	3.956147	0.457455	-1.394394
32	6	0	3.264782	0.094922	-0.224667
33	6	0	3.600394	-1.088054	0.420072
34	6	0	4.586472	-1.905390	-0.149104
35	6	0	5.243450	-1.548367	-1.324883
36	6	0	4.934644	-0.340648	-1.957514
37	8	0	3.872816	2.440828	-2.798122
38	1	0	-3.774723	1.850869	1.448263
39	1	0	-6.303864	-0.215938	-2.345197
40	1	0	-7.166536	1.837545	-1.199476
41	1	0	-5.908642	2.840538	0.667373
42	1	0	-1.541135	0.506232	1.741200
43	1	0	-1.777048	-3.446673	-1.415864
44	1	0	-2.079295	-3.241245	1.838090
45	1	0	-1.258462	-4.590233	1.021315
46	1	0	-0.388037	-3.625527	2.240889
47	1	0	0.470919	-3.944023	-0.988353
48	1	0	1.183008	-2.328141	-0.856880
49	1	0	1.938175	4.179995	-1.501057
50	1	0	-1.320782	3.058488	1.922592
51	1	0	-0.409248	2.027693	3.053484
52	1	0	-0.035711	3.739262	2.908430
53	1	0	-0.969447	4.743200	0.351485
54	1	0	0.326680	5.417847	1.335076
55	1	0	0.386993	5.572154	-0.427202
56	1	0	3.117172	-1.398912	1.337964
57	1	0	4.835592	-2.838890	0.346236
58	1	0	6.002555	-2.202798	-1.740535
59	1	0	5.445922	-0.022308	-2.861203

Free Energy and Geometry 39* (Conformer 6 of 21):



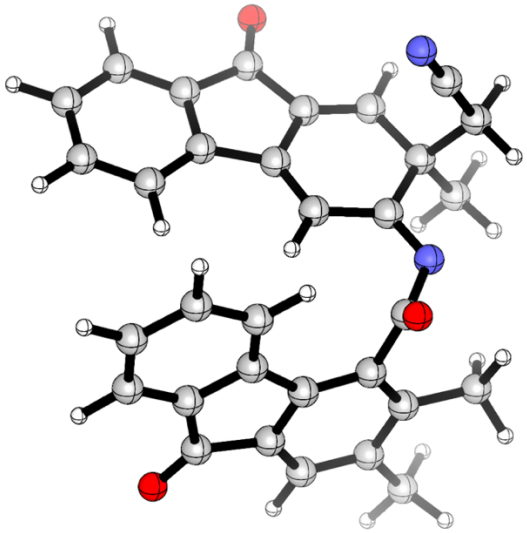
Sum of electronic and thermal free energies: -1566.810381 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	2.948285	1.745552	-0.138585
2	6	0	3.005541	0.388949	0.171673
3	6	0	4.102795	-0.140748	0.868735
4	6	0	5.165191	0.661874	1.264594
5	6	0	5.110556	2.017535	0.950273
6	6	0	4.013488	2.549958	0.258532
7	6	0	3.908275	-1.604762	1.087976
8	6	0	2.586135	-1.921509	0.457524
9	6	0	2.040058	-0.683107	-0.102743
10	6	0	0.845519	-0.648994	-0.715415
11	6	0	0.028170	-1.860543	-0.770510
12	6	0	0.653619	-3.214275	-0.407559
13	6	0	1.953427	-3.090317	0.352702
14	8	0	4.654669	-2.374719	1.652510
15	6	0	0.972748	-3.950906	-1.729834
16	6	0	-0.328845	-4.048814	0.453288
17	6	0	-1.485642	-4.581800	-0.275694
18	7	0	-2.389581	-5.058901	-0.815305
19	7	0	-1.198179	-1.863703	-1.133889
20	6	0	-1.872606	-0.697703	-1.504621
21	8	0	-2.022104	-0.374826	-2.664349
22	6	0	-2.425190	0.090629	-0.347574
23	6	0	-2.030510	1.418126	-0.169491
24	6	0	-2.424823	2.078769	1.003214
25	6	0	-3.236800	1.488003	1.949116

26	6	0	-3.693449	0.182964	1.742932
27	6	0	-3.277884	-0.522850	0.598553
28	6	0	-3.786408	-1.929752	0.398334
29	6	0	-4.609358	-0.461928	2.750088
30	6	0	-1.789415	3.427473	1.054190
31	6	0	-0.991007	3.529717	-0.203813
32	6	0	-1.159973	2.353145	-0.957074
33	6	0	-0.556439	2.266031	-2.207808
34	6	0	0.235824	3.335813	-2.648981
35	6	0	0.416485	4.481585	-1.877656
36	6	0	-0.216839	4.589895	-0.635776
37	8	0	-1.893543	4.258543	1.930647
38	1	0	2.099407	2.167339	-0.671918
39	1	0	6.005592	0.235468	1.803336
40	1	0	5.922982	2.673713	1.244645
41	1	0	3.993339	3.610870	0.030058
42	1	0	0.441391	0.271977	-1.121728
43	1	0	2.392597	-4.001181	0.756807
44	1	0	1.694917	-3.377105	-2.316264
45	1	0	1.395144	-4.938491	-1.521312
46	1	0	0.054168	-4.066230	-2.312105
47	1	0	0.206118	-4.908844	0.870769
48	1	0	-0.694181	-3.449818	1.293467
49	1	0	-3.515658	2.039290	2.843628
50	1	0	-3.582355	-2.318125	-0.598810
51	1	0	-3.326900	-2.619352	1.117269
52	1	0	-4.866927	-1.967410	0.567147
53	1	0	-5.598299	-0.657040	2.320305
54	1	0	-4.214283	-1.423137	3.094966
55	1	0	-4.742505	0.184940	3.619695
56	1	0	-0.696798	1.403185	-2.847405
57	1	0	0.711437	3.267033	-3.622419
58	1	0	1.033474	5.293211	-2.248937
59	1	0	-0.116083	5.477891	-0.018839

Free Energy and Geometry 39* (Conformer 7 of 21):



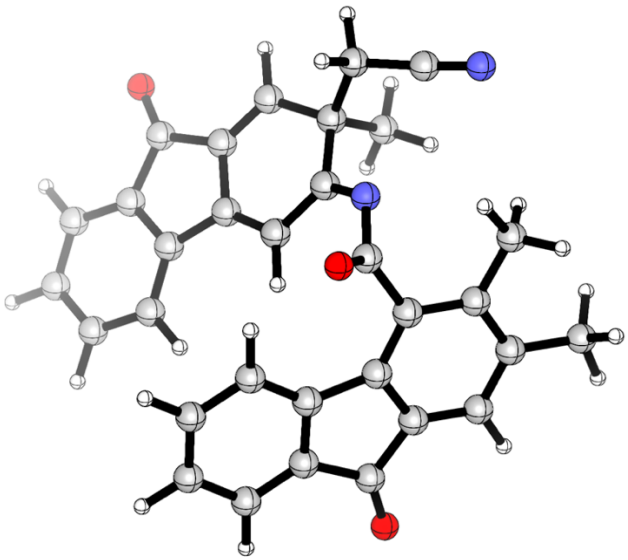
Sum of electronic and thermal free energies: -1566.812808 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-1.623297	2.772939	0.208877
2	6	0	-2.335031	1.611614	0.500334
3	6	0	-3.582290	1.677755	1.140897
4	6	0	-4.147272	2.894014	1.502457
5	6	0	-3.436374	4.055375	1.210280
6	6	0	-2.189979	3.992236	0.571460
7	6	0	-4.126541	0.301691	1.338218
8	6	0	-3.094831	-0.614004	0.751613
9	6	0	-1.993622	0.207001	0.243298
10	6	0	-0.907697	-0.332594	-0.335494
11	6	0	-0.799218	-1.781472	-0.465760
12	6	0	-1.944813	-2.686972	0.023177
13	6	0	-3.094078	-1.943489	0.656312
14	8	0	-5.173293	-0.012949	1.861159
15	6	0	-1.380900	-3.696039	1.040578
16	6	0	-2.478849	-3.481279	-1.199015
17	6	0	-3.043266	-2.592856	-2.220865
18	7	0	-3.479851	-1.869734	-3.009351
19	7	0	0.208452	-2.376464	-0.988693
20	6	0	1.335007	-1.685460	-1.444708
21	8	0	1.550000	-1.515934	-2.626348
22	6	0	2.284155	-1.221750	-0.370070
23	6	0	2.602025	0.134435	-0.272494
24	6	0	3.391159	0.560392	0.805225

25	6	0	3.906466	-0.315849	1.737751
26	6	0	3.640007	-1.682287	1.614891
27	6	0	2.819874	-2.136307	0.564776
28	6	0	2.557595	-3.618616	0.453754
29	6	0	4.218765	-2.653805	2.610198
30	6	0	3.506933	2.047810	0.782126
31	6	0	2.718762	2.481358	-0.409646
32	6	0	2.203522	1.346408	-1.062969
33	6	0	1.466883	1.520280	-2.230447
34	6	0	1.235796	2.824253	-2.691477
35	6	0	1.736285	3.938431	-2.021888
36	6	0	2.500791	3.768426	-0.863588
37	8	0	4.104442	2.751964	1.567481
38	1	0	-0.656430	2.733108	-0.287679
39	1	0	-5.113323	2.926280	1.996457
40	1	0	-3.848032	5.022860	1.478250
41	1	0	-1.656667	4.912493	0.355371
42	1	0	-0.107035	0.289266	-0.719905
43	1	0	-3.927412	-2.534376	1.034000
44	1	0	-0.968940	-3.170089	1.906156
45	1	0	-2.170452	-4.370682	1.384313
46	1	0	-0.584500	-4.279774	0.571754
47	1	0	-1.649293	-4.042335	-1.639894
48	1	0	-3.249689	-4.189746	-0.879767
49	1	0	4.512011	0.060647	2.558374
50	1	0	1.895354	-3.957239	1.259694
51	1	0	2.094701	-3.893798	-0.493335
52	1	0	3.493871	-4.176186	0.552059
53	1	0	3.439993	-3.275298	3.064401
54	1	0	4.934968	-3.332782	2.133842
55	1	0	4.740282	-2.121970	3.408612
56	1	0	1.079454	0.678132	-2.790912
57	1	0	0.655747	2.962058	-3.598593
58	1	0	1.541729	4.934137	-2.406499
59	1	0	2.918464	4.614204	-0.325512

Free Energy and Geometry 39* (Conformer 8 of 21):



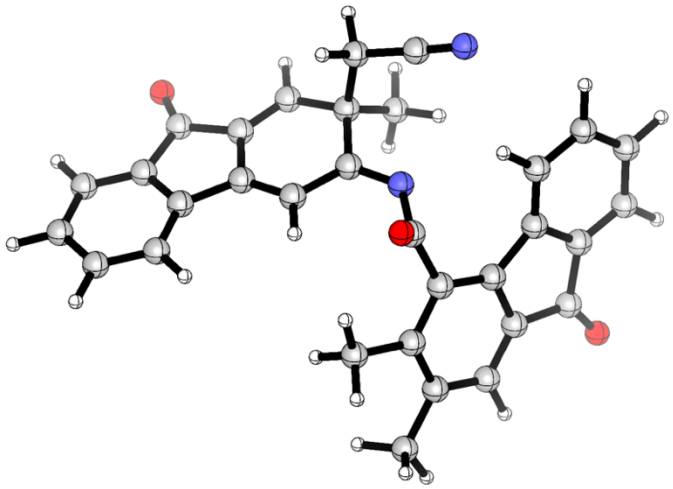
Sum of electronic and thermal free energies: -1566.811374 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-2.727873	2.262686	0.280656
2	6	0	-3.079648	0.915851	0.324739
3	6	0	-4.403308	0.531271	0.590580
4	6	0	-5.399997	1.471638	0.817672
5	6	0	-5.047970	2.818359	0.774707
6	6	0	-3.727214	3.205687	0.509034
7	6	0	-4.514244	-0.957365	0.577381
8	6	0	-3.129575	-1.449154	0.286710
9	6	0	-2.257434	-0.283638	0.113476
10	6	0	-0.963362	-0.412202	-0.223791
11	6	0	-0.424271	-1.749510	-0.481112
12	6	0	-1.191657	-2.965708	0.047207
13	6	0	-2.668684	-2.699120	0.222522
14	8	0	-5.506186	-1.627417	0.766829
15	6	0	-0.633012	-3.270032	1.461151
16	6	0	-0.999851	-4.186235	-0.883753
17	6	0	0.332485	-4.796257	-0.807695
18	7	0	1.354531	-5.330657	-0.729731
19	7	0	0.676991	-1.966393	-1.092347
20	6	0	1.501757	-0.936471	-1.553034
21	8	0	1.489128	-0.576606	-2.711568
22	6	0	2.428366	-0.351925	-0.522863
23	6	0	2.390131	1.020203	-0.267182
24	6	0	3.177320	1.526368	0.776813
25	6	0	4.018791	0.727336	1.523400

26	6	0	4.102080	-0.638387	1.237621
27	6	0	3.301132	-1.182884	0.216115
28	6	0	3.421560	-2.656586	-0.085198
29	6	0	5.036078	-1.516697	2.028533
30	6	0	2.906164	2.983574	0.944872
31	6	0	1.886136	3.312723	-0.095212
32	6	0	1.592477	2.155549	-0.840335
33	6	0	0.686254	2.246908	-1.892135
34	6	0	0.076786	3.483433	-2.149118
35	6	0	0.366054	4.615552	-1.391090
36	6	0	1.294259	4.535470	-0.348592
37	8	0	3.400298	3.736433	1.756603
38	1	0	-1.706743	2.572494	0.072675
39	1	0	-6.418218	1.154829	1.020687
40	1	0	-5.801242	3.579899	0.947551
41	1	0	-3.479300	4.261961	0.480110
42	1	0	-0.329601	0.451630	-0.396105
43	1	0	-3.329140	-3.548991	0.387527
44	1	0	-0.803297	-2.419204	2.125524
45	1	0	-1.128157	-4.150227	1.881762
46	1	0	0.442031	-3.462203	1.395781
47	1	0	-1.722139	-4.961902	-0.607631
48	1	0	-1.194147	-3.903886	-1.922397
49	1	0	4.609040	1.163276	2.325535
50	1	0	4.475376	-2.947465	-0.129670
51	1	0	2.954300	-3.261051	0.701474
52	1	0	2.948803	-2.937980	-1.025396
53	1	0	4.512154	-2.379454	2.452696
54	1	0	5.842801	-1.908549	1.398874
55	1	0	5.491129	-0.955688	2.847490
56	1	0	0.452485	1.394554	-2.517972
57	1	0	-0.634174	3.555325	-2.966449
58	1	0	-0.120196	5.558571	-1.618117
59	1	0	1.553280	5.401509	0.253212

Free Energy and Geometry 39* (Conformer 9 of 21):



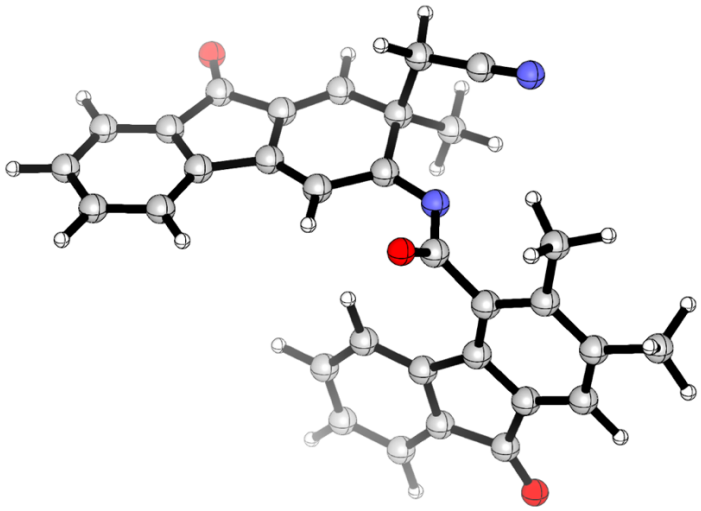
Sum of electronic and thermal free energies: -1566.811211 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-4.604145	-1.793861	0.802711
2	6	0	-4.299817	-0.618298	0.120768
3	6	0	-5.255713	-0.015896	-0.713221
4	6	0	-6.521125	-0.561990	-0.884601
5	6	0	-6.823224	-1.736452	-0.200684
6	6	0	-5.873097	-2.342395	0.632451
7	6	0	-4.690557	1.220036	-1.326616
8	6	0	-3.299594	1.323914	-0.782745
9	6	0	-3.060707	0.175108	0.097945
10	6	0	-1.872097	-0.022411	0.694858
11	6	0	-0.771536	0.907005	0.426859
12	6	0	-1.044959	2.232813	-0.303104
13	6	0	-2.386652	2.271827	-0.990800
14	8	0	-5.236227	1.982708	-2.094442
15	6	0	0.067593	2.530488	-1.319226
16	6	0	-1.102875	3.361191	0.775762
17	6	0	0.192217	3.619123	1.414112
18	7	0	1.208040	3.860801	1.909882
19	7	0	0.438881	0.693428	0.778774
20	6	0	0.855651	-0.394887	1.539883
21	8	0	0.591619	-0.519101	2.719109
22	6	0	1.723907	-1.344334	0.760422
23	6	0	2.868334	-0.885913	0.105785
24	6	0	3.595139	-1.777408	-0.691830
25	6	0	3.219558	-3.095664	-0.853064
26	6	0	2.091910	-3.573551	-0.180220
27	6	0	1.347960	-2.702153	0.639903

28	6	0	0.124494	-3.250775	1.334269
29	6	0	1.676761	-5.013132	-0.342169
30	6	0	4.757489	-1.062295	-1.301370
31	6	0	4.686346	0.327526	-0.760666
32	6	0	3.573842	0.433895	0.092073
33	6	0	3.350594	1.624578	0.770604
34	6	0	4.224877	2.695977	0.547664
35	6	0	5.310532	2.586324	-0.319744
36	6	0	5.556050	1.380086	-0.981604
37	8	0	5.579836	-1.519223	-2.066697
38	1	0	-3.876396	-2.272837	1.450750
39	1	0	-7.243420	-0.078689	-1.535032
40	1	0	-7.802228	-2.191004	-0.310690
41	1	0	-6.132718	-3.257460	1.154963
42	1	0	-1.680824	-0.874144	1.339585
43	1	0	-2.597544	3.120580	-1.639784
44	1	0	0.082763	1.762404	-2.096610
45	1	0	-0.107914	3.502441	-1.790443
46	1	0	1.041212	2.539429	-0.822825
47	1	0	-1.429976	4.293213	0.302459
48	1	0	-1.834201	3.108567	1.550156
49	1	0	3.803304	-3.752466	-1.493178
50	1	0	-0.237221	-2.588803	2.118778
51	1	0	-0.683833	-3.422969	0.612341
52	1	0	0.348429	-4.216622	1.796085
53	1	0	1.755815	-5.561246	0.603389
54	1	0	0.637035	-5.096011	-0.675978
55	1	0	2.310719	-5.515697	-1.075605
56	1	0	2.519373	1.753181	1.452112
57	1	0	4.040429	3.630293	1.069226
58	1	0	5.969380	3.434948	-0.472316
59	1	0	6.404611	1.257355	-1.648162

Free Energy and Geometry 39* (Conformer 10 of 21):



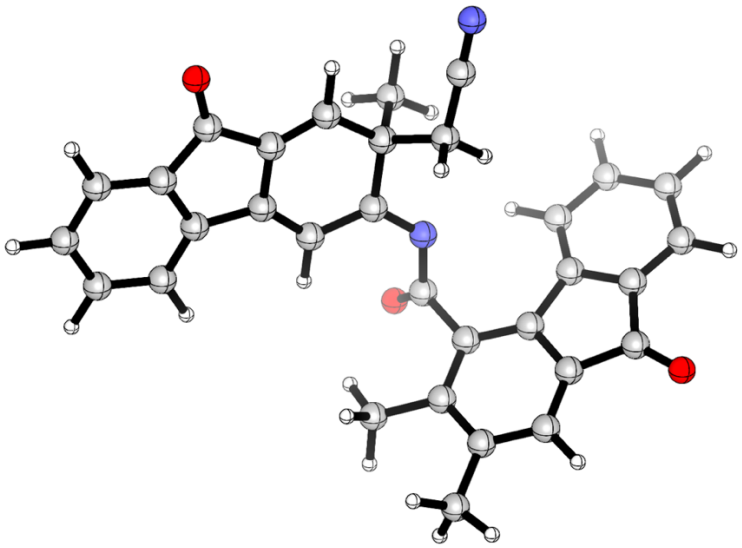
Sum of electronic and thermal free energies: -1566.807880 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	3.950671	1.332734	2.136268
2	6	0	3.966474	0.599802	0.952168
3	6	0	5.118820	0.574163	0.149457
4	6	0	6.268425	1.268060	0.502710
5	6	0	6.250395	1.999279	1.687660
6	6	0	5.103506	2.028907	2.492412
7	6	0	4.881590	-0.273816	-1.054063
8	6	0	3.477375	-0.772091	-0.907321
9	6	0	2.914005	-0.213952	0.323829
10	6	0	1.642229	-0.451961	0.703128
11	6	0	0.777918	-1.249314	-0.165525
12	6	0	1.394651	-2.038070	-1.333640
13	6	0	2.793427	-1.606117	-1.689811
14	8	0	5.654916	-0.516523	-1.954716
15	6	0	0.499648	-1.965909	-2.579493
16	6	0	1.536218	-3.522125	-0.859976
17	6	0	0.249972	-4.175608	-0.595780
18	7	0	-0.750430	-4.718258	-0.394931
19	7	0	-0.498250	-1.370598	-0.036769
20	6	0	-1.216023	-0.903390	1.065988
21	8	0	-0.834465	-0.967406	2.218614
22	6	0	-2.619869	-0.472754	0.723790
23	6	0	-2.906785	0.765913	0.168531
24	6	0	-4.241065	1.100589	-0.101295
25	6	0	-5.280371	0.236838	0.176111
26	6	0	-5.002962	-1.017293	0.734974

27	6	0	-3.669020	-1.377112	0.998856
28	6	0	-3.336759	-2.728426	1.583478
29	6	0	-6.138163	-1.961251	1.043811
30	6	0	-4.290950	2.466542	-0.704925
31	6	0	-2.865432	2.920307	-0.763668
32	6	0	-2.043998	1.910887	-0.234076
33	6	0	-0.674783	2.113175	-0.161302
34	6	0	-0.149275	3.322564	-0.633937
35	6	0	-0.971830	4.313724	-1.165398
36	6	0	-2.355167	4.116753	-1.230990
37	8	0	-5.272512	3.078147	-1.068874
38	1	0	3.068004	1.363161	2.767503
39	1	0	7.147408	1.234011	-0.133284
40	1	0	7.131021	2.553493	1.995145
41	1	0	5.114950	2.606348	3.411121
42	1	0	1.226061	-0.043805	1.616622
43	1	0	3.240528	-2.026160	-2.589532
44	1	0	0.414334	-0.931309	-2.921310
45	1	0	0.932988	-2.567099	-3.384442
46	1	0	-0.499949	-2.336201	-2.346775
47	1	0	2.050834	-4.096097	-1.637818
48	1	0	2.146700	-3.572273	0.047390
49	1	0	-6.304498	0.530405	-0.040290
50	1	0	-2.401134	-3.119438	1.172355
51	1	0	-3.218845	-2.661693	2.670969
52	1	0	-4.119321	-3.458739	1.374016
53	1	0	-6.091482	-2.862270	0.422526
54	1	0	-6.116754	-2.285281	2.089122
55	1	0	-7.099246	-1.476718	0.858517
56	1	0	-0.008223	1.367515	0.257017
57	1	0	0.922600	3.487749	-0.581163
58	1	0	-0.536686	5.240611	-1.524077
59	1	0	-3.019283	4.875749	-1.633716

Free Energy and Geometry 39* (Conformer 11 of 21):



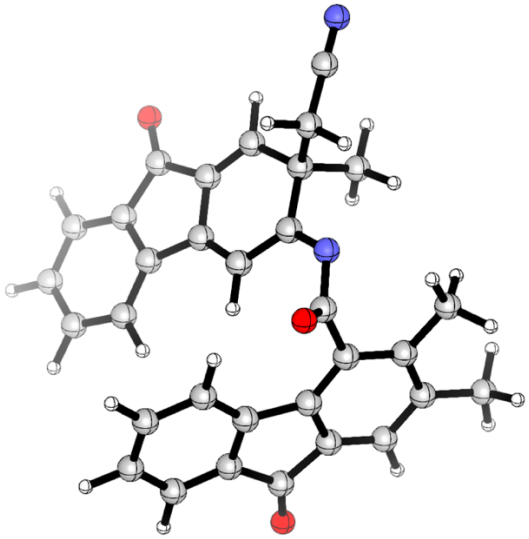
Sum of electronic and thermal free energies: -1566.812329 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	4.657600	-2.103543	0.706400
2	6	0	4.385725	-0.823887	0.229021
3	6	0	5.391026	-0.075716	-0.404332
4	6	0	6.674441	-0.577513	-0.575491
5	6	0	6.943888	-1.857155	-0.097059
6	6	0	5.944692	-2.608286	0.536211
7	6	0	4.852226	1.251624	-0.819889
8	6	0	3.423127	1.248746	-0.374482
9	6	0	3.139520	-0.041921	0.259947
10	6	0	1.916212	-0.353675	0.727720
11	6	0	0.828504	0.610042	0.577715
12	6	0	1.133670	2.042245	0.108981
13	6	0	2.508557	2.212840	-0.480432
14	8	0	5.441180	2.143282	-1.391228
15	6	0	1.043297	2.949624	1.358975
16	6	0	0.046362	2.456154	-0.916654
17	6	0	0.204810	3.847939	-1.345858
18	7	0	0.355704	4.947754	-1.668089
19	7	0	-0.402364	0.359032	0.833304
20	6	0	-0.859527	-0.825390	1.403319
21	8	0	-0.510733	-1.223399	2.497578
22	6	0	-1.894080	-1.505006	0.549669
23	6	0	-3.046044	-0.821209	0.157730
24	6	0	-3.942769	-1.450188	-0.713618
25	6	0	-3.728653	-2.725673	-1.196531

26	6	0	-2.593099	-3.430299	-0.788976
27	6	0	-1.677321	-2.825159	0.094909
28	6	0	-0.447904	-3.606128	0.490432
29	6	0	-2.351199	-4.826142	-1.302044
30	6	0	-5.080129	-0.526892	-1.005867
31	6	0	-4.806845	0.696640	-0.193373
32	6	0	-3.606187	0.520146	0.516332
33	6	0	-3.196735	1.506203	1.405829
34	6	0	-3.979859	2.660642	1.534359
35	6	0	-5.153415	2.834424	0.803103
36	6	0	-5.584300	1.833570	-0.071473
37	8	0	-6.022876	-0.731485	-1.740092
38	1	0	3.891980	-2.694578	1.199581
39	1	0	7.435438	0.019448	-1.068264
40	1	0	7.935994	-2.280815	-0.212924
41	1	0	6.179736	-3.602851	0.901313
42	1	0	1.698421	-1.310699	1.189362
43	1	0	2.750900	3.167708	-0.945635
44	1	0	1.769283	2.632573	2.112066
45	1	0	1.248504	3.989892	1.090623
46	1	0	0.036739	2.877336	1.782716
47	1	0	0.087665	1.810640	-1.799429
48	1	0	-0.939685	2.330461	-0.458691
49	1	0	-4.443387	-3.173826	-1.882140
50	1	0	0.087786	-3.145312	1.318066
51	1	0	-0.721751	-4.619423	0.798842
52	1	0	0.234942	-3.705932	-0.362038
53	1	0	-1.372609	-4.911453	-1.786314
54	1	0	-2.372440	-5.560209	-0.488797
55	1	0	-3.116141	-5.107349	-2.028777
56	1	0	-2.294161	1.401223	1.995696
57	1	0	-3.663247	3.435478	2.225793
58	1	0	-5.736228	3.741528	0.923853
59	1	0	-6.505232	1.929149	-0.638937

Free Energy and Geometry 39* (Conformer 12 of 21):



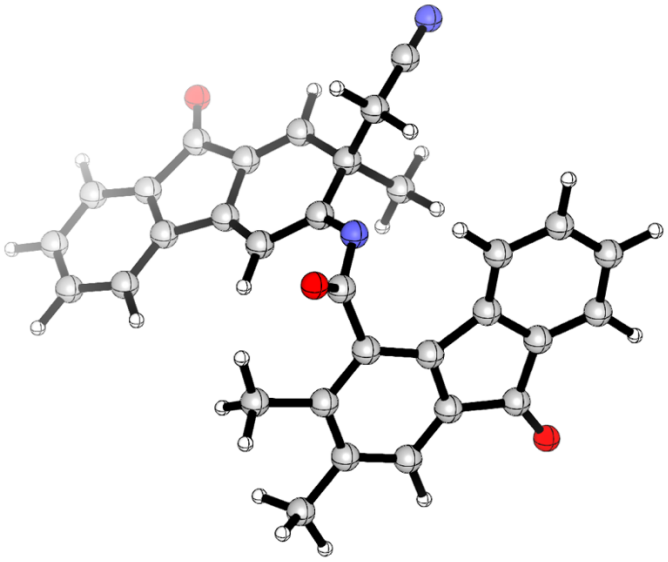
Sum of electronic and thermal free energies: -1566.813212 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-0.779962	3.243774	0.184209
2	6	0	-1.811087	2.321452	0.346376
3	6	0	-3.064537	2.726329	0.831336
4	6	0	-3.319207	4.050577	1.163772
5	6	0	-2.288353	4.973075	1.002000
6	6	0	-1.035368	4.571558	0.518054
7	6	0	-3.983847	1.551941	0.909165
8	6	0	-3.171648	0.387856	0.427804
9	6	0	-1.836983	0.877821	0.078441
10	6	0	-0.884592	0.066472	-0.411694
11	6	0	-1.168399	-1.351190	-0.610338
12	6	0	-2.518404	-1.931777	-0.154498
13	6	0	-3.512814	-0.895422	0.306453
14	8	0	-5.136545	1.538653	1.281815
15	6	0	-2.237894	-2.884068	1.028328
16	6	0	-3.105671	-2.731148	-1.348392
17	6	0	-4.345959	-3.423219	-0.988241
18	7	0	-5.323140	-3.956267	-0.676727
19	7	0	-0.336139	-2.176451	-1.128786
20	6	0	0.945706	-1.794101	-1.535984
21	8	0	1.219185	-1.620739	-2.705253
22	6	0	1.965547	-1.664046	-0.435267
23	6	0	2.638380	-0.451675	-0.265639
24	6	0	3.497371	-0.312313	0.833474
25	6	0	3.743176	-1.342909	1.717105

26	6	0	3.119085	-2.577634	1.520627
27	6	0	2.220599	-2.737018	0.448555
28	6	0	1.575231	-4.087690	0.256777
29	6	0	3.401261	-3.721405	2.459238
30	6	0	4.013499	1.086391	0.890322
31	6	0	3.391624	1.778636	-0.277446
32	6	0	2.597201	0.862161	-0.991125
33	6	0	1.955272	1.290901	-2.148851
34	6	0	2.096521	2.630096	-2.539835
35	6	0	2.870697	3.529496	-1.810638
36	6	0	3.540656	3.097699	-0.661856
37	8	0	4.767739	1.560454	1.712376
38	1	0	0.194864	2.941166	-0.191251
39	1	0	-4.294719	4.345994	1.537144
40	1	0	-2.452266	6.016019	1.252384
41	1	0	-0.249138	5.310702	0.401594
42	1	0	0.091290	0.447935	-0.690216
43	1	0	-4.511351	-1.239017	0.574385
44	1	0	-1.766396	-2.338259	1.850071
45	1	0	-3.168819	-3.328363	1.392062
46	1	0	-1.563178	-3.678566	0.696330
47	1	0	-3.309048	-2.064038	-2.191861
48	1	0	-2.364760	-3.467024	-1.674028
49	1	0	4.416844	-1.188226	2.556118
50	1	0	0.870289	-4.299925	1.069342
51	1	0	1.032359	-4.166574	-0.684212
52	1	0	2.335559	-4.874574	0.280738
53	1	0	2.478768	-4.123840	2.890705
54	1	0	3.900558	-4.547748	1.940938
55	1	0	4.047962	-3.397847	3.277384
56	1	0	1.362301	0.616512	-2.754362
57	1	0	1.591808	2.967396	-3.439787
58	1	0	2.961708	4.558737	-2.141622
59	1	0	4.164680	3.767907	-0.078148

Free Energy and Geometry 39* (Conformer 13 of 21):



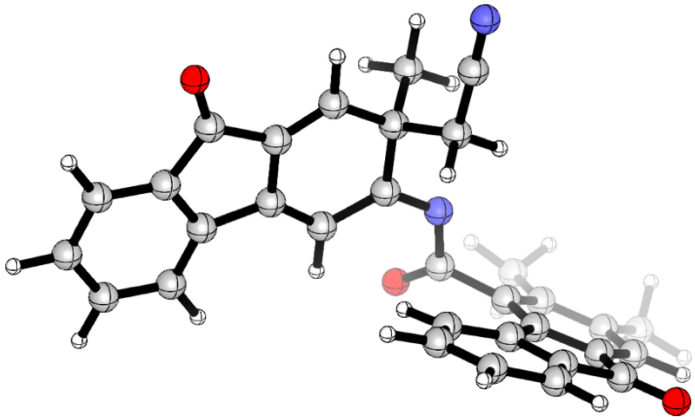
Sum of electronic and thermal free energies: -1566.811095 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	4.179563	2.153134	0.187519
2	6	0	3.962043	0.805134	-0.086068
3	6	0	4.984389	0.022690	-0.646454
4	6	0	6.230786	0.557055	-0.944966
5	6	0	6.445133	1.905493	-0.672016
6	6	0	5.428985	2.691213	-0.112041
7	6	0	4.507213	-1.377369	-0.839073
8	6	0	3.092124	-1.377396	-0.351631
9	6	0	2.767147	-0.028351	0.122484
10	6	0	1.569219	0.264089	0.660990
11	6	0	0.566029	-0.791224	0.799339
12	6	0	0.793430	-2.151252	0.120919
13	6	0	2.211763	-2.378326	-0.330517
14	8	0	5.126683	-2.313839	-1.294570
15	6	0	-0.105377	-2.168365	-1.139743
16	6	0	0.341285	-3.264592	1.098477
17	6	0	0.439647	-4.595179	0.493009
18	7	0	0.530648	-5.632901	-0.007924
19	7	0	-0.546333	-0.642870	1.411053
20	6	0	-0.998056	0.554648	1.962172
21	8	0	-0.888897	0.811849	3.142788
22	6	0	-1.701588	1.437933	0.965303
23	6	0	-2.723266	0.929749	0.158800
24	6	0	-3.261490	1.743757	-0.843989

25	6	0	-2.833988	3.039908	-1.051598
26	6	0	-1.847146	3.575183	-0.221406
27	6	0	-1.280990	2.777468	0.794567
28	6	0	-0.209088	3.400730	1.655498
29	6	0	-1.390476	4.996983	-0.419214
30	6	0	-4.303471	0.982507	-1.596683
31	6	0	-4.384000	-0.343958	-0.915556
32	6	0	-3.465061	-0.372664	0.147754
33	6	0	-3.442758	-1.478770	0.989327
34	6	0	-4.308212	-2.546249	0.717527
35	6	0	-5.189799	-2.518159	-0.361554
36	6	0	-5.240787	-1.394310	-1.189785
37	8	0	-4.947351	1.365564	-2.549641
38	1	0	3.401569	2.772667	0.623322
39	1	0	7.005932	-0.067876	-1.377284
40	1	0	7.406907	2.356569	-0.892691
41	1	0	5.620842	3.739595	0.092427
42	1	0	1.337219	1.250345	1.052555
43	1	0	2.479588	-3.367966	-0.698970
44	1	0	0.166892	-1.348889	-1.810380
45	1	0	0.009772	-3.113527	-1.678082
46	1	0	-1.150623	-2.047356	-0.836214
47	1	0	0.948799	-3.247250	2.008423
48	1	0	-0.697903	-3.079895	1.385890
49	1	0	-3.273609	3.635799	-1.847456
50	1	0	-0.605057	4.285286	2.166172
51	1	0	0.167035	2.726215	2.421910
52	1	0	0.628011	3.745421	1.036782
53	1	0	-1.557105	5.599257	0.480515
54	1	0	-0.319571	5.047576	-0.644667
55	1	0	-1.932220	5.463954	-1.244175
56	1	0	-2.776691	-1.530985	1.841676
57	1	0	-4.292357	-3.413779	1.370097
58	1	0	-5.844988	-3.362853	-0.546704
59	1	0	-5.935348	-1.329553	-2.022009

Free Energy and Geometry 39* (Conformer 14 of 21):



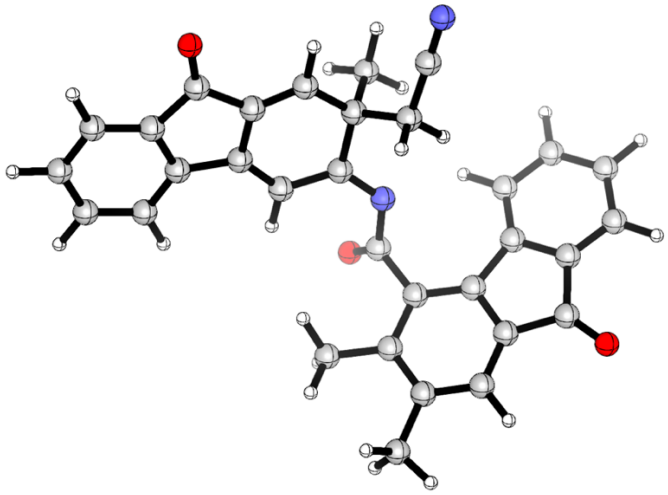
Sum of electronic and thermal free energies: -1566.810148 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	3.996597	-1.751544	-2.168623
2	6	0	3.991690	-0.956363	-1.025298
3	6	0	5.161265	-0.295724	-0.615371
4	6	0	6.348515	-0.408454	-1.325992
5	6	0	6.350774	-1.203705	-2.469446
6	6	0	5.187183	-1.866246	-2.882613
7	6	0	4.895167	0.481691	0.629737
8	6	0	3.452156	0.233068	0.941906
9	6	0	2.902049	-0.650970	-0.085608
10	6	0	1.613471	-1.053493	-0.080801
11	6	0	0.724563	-0.586561	0.974367
12	6	0	1.272549	0.302187	2.106218
13	6	0	2.716324	0.694204	1.953225
14	8	0	5.673649	1.167095	1.255449
15	6	0	1.116677	-0.469726	3.434119
16	6	0	0.392243	1.585165	2.132177
17	6	0	0.768047	2.485482	3.224761
18	7	0	1.087286	3.176686	4.094554
19	7	0	-0.544473	-0.816161	1.048951
20	6	0	-1.222703	-1.677786	0.179509
21	8	0	-0.770344	-2.717891	-0.261925
22	6	0	-2.657924	-1.274451	-0.034015
23	6	0	-2.987871	-0.034719	-0.579197
24	6	0	-4.334404	0.339708	-0.661999
25	6	0	-5.354562	-0.497729	-0.258186
26	6	0	-5.040488	-1.760517	0.250741
27	6	0	-3.690649	-2.148259	0.376159
28	6	0	-3.391784	-3.500255	0.976407

29	6	0	-6.147033	-2.690115	0.678032
30	6	0	-4.429873	1.728440	-1.203080
31	6	0	-3.018655	2.133782	-1.487291
32	6	0	-2.162842	1.068872	-1.156272
33	6	0	-0.811621	1.172990	-1.455563
34	6	0	-0.335393	2.363997	-2.019913
35	6	0	-1.188786	3.428813	-2.301069
36	6	0	-2.558777	3.310381	-2.047966
37	8	0	-5.434291	2.383455	-1.380271
38	1	0	3.101609	-2.270613	-2.497224
39	1	0	7.240619	0.111127	-0.990669
40	1	0	7.261127	-1.315083	-3.049175
41	1	0	5.215639	-2.481081	-3.776339
42	1	0	1.217500	-1.721737	-0.835825
43	1	0	3.147023	1.351038	2.708221
44	1	0	1.714285	-1.384704	3.412695
45	1	0	1.452238	0.146904	4.272916
46	1	0	0.065629	-0.734679	3.574638
47	1	0	0.477859	2.126116	1.183413
48	1	0	-0.652458	1.283844	2.250110
49	1	0	-6.389185	-0.174261	-0.340073
50	1	0	-3.611320	-4.295034	0.253715
51	1	0	-2.350359	-3.609595	1.273292
52	1	0	-4.021941	-3.678321	1.852021
53	1	0	-6.052686	-3.670898	0.200607
54	1	0	-6.134709	-2.856669	1.761125
55	1	0	-7.121568	-2.274233	0.413878
56	1	0	-0.123395	0.351779	-1.294036
57	1	0	0.722020	2.450055	-2.251233
58	1	0	-0.791339	4.339335	-2.736883
59	1	0	-3.253830	4.108799	-2.290076

Free Energy and Geometry 39* (Conformer 15 of 21):



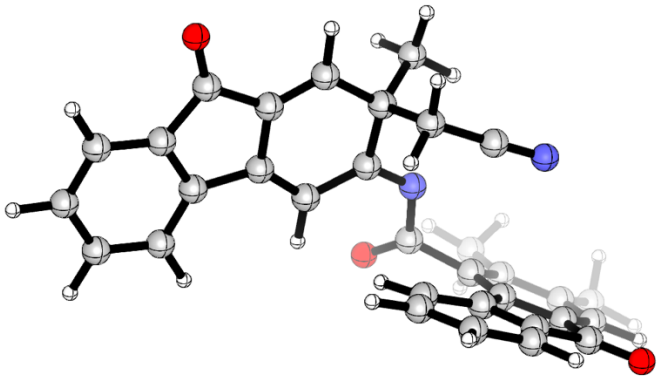
Sum of electronic and thermal free energies: -1566.812246 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	4.708659	2.151824	-0.728185
2	6	0	4.444640	0.873624	-0.242510
3	6	0	5.460991	0.126120	0.373890
4	6	0	6.747852	0.626901	0.519485
5	6	0	7.009473	1.905020	0.032524
6	6	0	5.999271	2.655575	-0.583700
7	6	0	4.928558	-1.199324	0.803538
8	6	0	3.491590	-1.195757	0.384570
9	6	0	3.196851	0.093553	-0.246263
10	6	0	1.964777	0.408053	-0.690819
11	6	0	0.877187	-0.550530	-0.510403
12	6	0	1.198130	-1.989100	-0.072631
13	6	0	2.579557	-2.161094	0.500621
14	8	0	5.527148	-2.090396	1.365616
15	6	0	1.110672	-2.868243	-1.344106
16	6	0	0.122637	-2.440780	0.948757
17	6	0	0.303570	-3.839405	1.345562
18	7	0	0.471761	-4.944040	1.641742
19	7	0	-0.365653	-0.297514	-0.712887
20	6	0	-0.837776	0.896625	-1.252936
21	8	0	-0.431518	1.384943	-2.289481
22	6	0	-1.958514	1.494680	-0.450711
23	6	0	-3.104719	0.764302	-0.141640
24	6	0	-4.091756	1.369149	0.648292
25	6	0	-3.976341	2.663615	1.109611
26	6	0	-2.842868	3.416014	0.781278
27	6	0	-1.827876	2.827728	0.004836

28	6	0	-0.587604	3.619425	-0.337389
29	6	0	-2.735624	4.839799	1.269178
30	6	0	-5.209194	0.404422	0.871949
31	6	0	-4.826923	-0.817997	0.103954
32	6	0	-3.585395	-0.602898	-0.519800
33	6	0	-3.076730	-1.584265	-1.362211
34	6	0	-3.802880	-2.771002	-1.526819
35	6	0	-5.018030	-2.981954	-0.878024
36	6	0	-5.549109	-1.986561	-0.054008
37	8	0	-6.212927	0.580361	1.528868
38	1	0	3.934280	2.742559	-1.207747
39	1	0	7.517396	0.030543	0.999548
40	1	0	8.003995	2.327985	0.128539
41	1	0	6.228347	3.649016	-0.955577
42	1	0	1.742930	1.360324	-1.158962
43	1	0	2.829572	-3.118228	0.956965
44	1	0	1.826826	-2.524044	-2.094629
45	1	0	1.331769	-3.911488	-1.101127
46	1	0	0.100210	-2.801353	-1.759288
47	1	0	0.159865	-1.814381	1.845318
48	1	0	-0.868078	-2.319188	0.500356
49	1	0	-4.768208	3.093800	1.717602
50	1	0	-0.454733	4.464403	0.338191
51	1	0	0.311169	3.000610	-0.275133
52	1	0	-0.642813	4.003560	-1.360875
53	1	0	-1.906267	4.964168	1.973845
54	1	0	-2.568767	5.536562	0.441806
55	1	0	-3.654145	5.136129	1.780183
56	1	0	-2.139604	-1.449605	-1.888090
57	1	0	-3.407274	-3.541818	-2.181175
58	1	0	-5.554790	-3.913355	-1.024512
59	1	0	-6.504499	-2.109704	0.447401

Free Energy and Geometry 39* (Conformer 16 of 21):



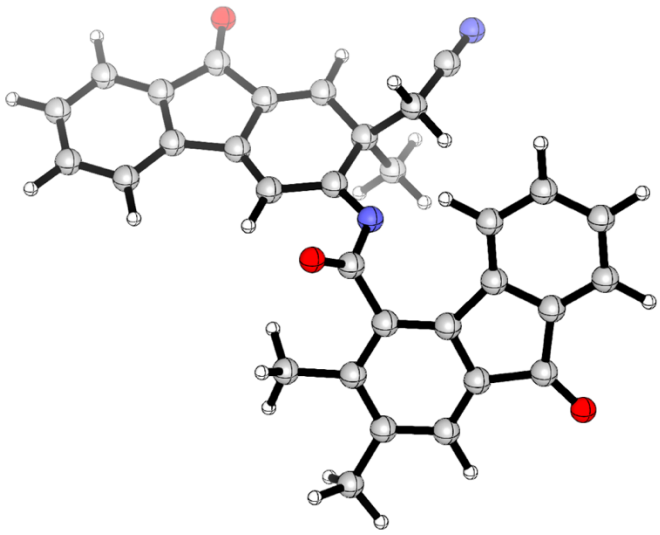
Sum of electronic and thermal free energies: -1566.807796 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	4.266221	-0.781793	-2.355864
2	6	0	4.190032	-0.469620	-1.000749
3	6	0	5.342083	-0.082272	-0.296816
4	6	0	6.581159	0.003040	-0.917575
5	6	0	6.654453	-0.308856	-2.272759
6	6	0	5.508494	-0.696452	-2.980157
7	6	0	4.998303	0.194738	1.127491
8	6	0	3.524917	-0.051441	1.226502
9	6	0	3.035921	-0.471961	-0.088220
10	6	0	1.748539	-0.811212	-0.301154
11	6	0	0.805395	-0.771458	0.813231
12	6	0	1.239126	-0.179637	2.166053
13	6	0	2.719206	0.073985	2.280343
14	8	0	5.743775	0.548128	2.015094
15	6	0	0.779124	-1.082450	3.321026
16	6	0	0.576465	1.231907	2.287525
17	6	0	-0.884582	1.202397	2.418831
18	7	0	-2.032139	1.228004	2.555141
19	7	0	-0.433706	-1.119471	0.758300
20	6	0	-1.042378	-1.666011	-0.376541
21	8	0	-0.523521	-2.478334	-1.119557
22	6	0	-2.490813	-1.265165	-0.484481
23	6	0	-2.855738	0.075203	-0.596039
24	6	0	-4.208109	0.427064	-0.532508
25	6	0	-5.205209	-0.520439	-0.413073
26	6	0	-4.857931	-1.872359	-0.356613
27	6	0	-3.498830	-2.249174	-0.379377
28	6	0	-3.169281	-3.716317	-0.256261
29	6	0	-5.936669	-2.918216	-0.243244
30	6	0	-4.332867	1.915041	-0.574270

31	6	0	-2.933041	2.419485	-0.731112
32	6	0	-2.059881	1.320703	-0.793326
33	6	0	-0.718146	1.538337	-1.068693
34	6	0	-0.263346	2.857035	-1.205957
35	6	0	-1.131383	3.940668	-1.091020
36	6	0	-2.495075	3.722712	-0.868455
37	8	0	-5.349003	2.572454	-0.506787
38	1	0	3.385748	-1.084401	-2.914112
39	1	0	7.458045	0.304342	-0.353147
40	1	0	7.606375	-0.253209	-2.790380
41	1	0	5.592008	-0.935193	-4.035449
42	1	0	1.402945	-1.179416	-1.260275
43	1	0	3.105774	0.394753	3.246571
44	1	0	1.284978	-2.049817	3.268710
45	1	0	1.019213	-0.613821	4.280351
46	1	0	-0.298452	-1.245093	3.258421
47	1	0	0.976952	1.736972	3.173277
48	1	0	0.830959	1.842958	1.414472
49	1	0	-6.246782	-0.213119	-0.364803
50	1	0	-3.486975	-4.253842	-1.157397
51	1	0	-2.105379	-3.901119	-0.122713
52	1	0	-3.708560	-4.159581	0.586414
53	1	0	-5.848807	-3.672201	-1.032634
54	1	0	-5.880842	-3.448185	0.714330
55	1	0	-6.925545	-2.460817	-0.317020
56	1	0	-0.022830	0.718736	-1.209685
57	1	0	0.787604	3.032326	-1.417093
58	1	0	-0.751471	4.951087	-1.199641
59	1	0	-3.200992	4.546016	-0.812709

Free Energy and Geometry 39* (Conformer 17 of 21):



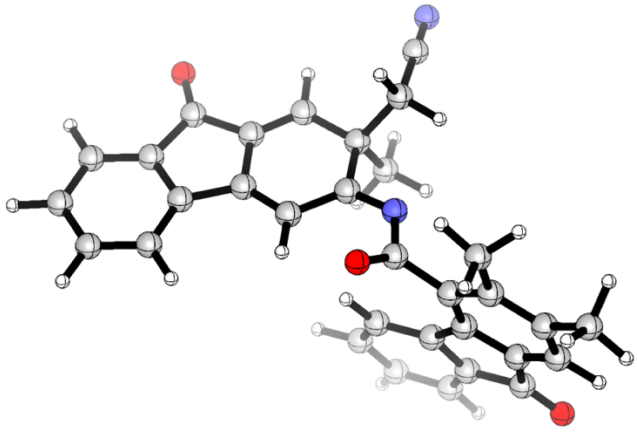
Sum of electronic and thermal free energies: -1566.812421 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	4.694570	-2.268366	-0.794746
2	6	0	4.494461	-0.974650	-0.319364
3	6	0	5.591437	-0.175212	0.040716
4	6	0	6.896301	-0.638183	-0.063170
5	6	0	7.093546	-1.931998	-0.538778
6	6	0	6.003002	-2.734680	-0.899209
7	6	0	5.116369	1.156218	0.516224
8	6	0	3.624248	1.094559	0.417703
9	6	0	3.248693	-0.220469	-0.107242
10	6	0	1.966328	-0.558721	-0.345890
11	6	0	0.910615	0.413636	-0.081641
12	6	0	1.248509	1.731196	0.636726
13	6	0	2.721495	2.021836	0.736530
14	8	0	5.788664	2.087421	0.902429
15	6	0	0.703543	1.613334	2.080829
16	6	0	0.513185	2.877218	-0.105658
17	6	0	0.709157	4.170100	0.554925
18	7	0	0.883748	5.177698	1.093809
19	7	0	-0.339453	0.238241	-0.335125
20	6	0	-0.835339	-0.886878	-0.993184
21	8	0	-0.372409	-1.346867	-2.018896
22	6	0	-2.067226	-1.443015	-0.335262
23	6	0	-3.218251	-0.674349	-0.196315
24	6	0	-4.325467	-1.228580	0.459092
25	6	0	-4.316061	-2.517287	0.951145

26	6	0	-3.172271	-3.309859	0.792422
27	6	0	-2.042402	-2.768354	0.153102
28	6	0	-0.787480	-3.592459	-0.012350
29	6	0	-3.176327	-4.725664	1.314185
30	6	0	-5.423296	-0.216104	0.511622
31	6	0	-4.887025	0.977831	-0.211568
32	6	0	-3.582351	0.700017	-0.653992
33	6	0	-2.913428	1.640025	-1.427180
34	6	0	-3.552344	2.855196	-1.705546
35	6	0	-4.835617	3.130198	-1.236003
36	6	0	-5.523984	2.174667	-0.483535
37	8	0	-6.515187	-0.339692	1.023511
38	1	0	3.858378	-2.900285	-1.077551
39	1	0	7.728426	-0.001598	0.220766
40	1	0	8.099742	-2.326858	-0.632882
41	1	0	6.182756	-3.739550	-1.267475
42	1	0	1.696374	-1.510126	-0.789685
43	1	0	3.025858	2.989152	1.134547
44	1	0	1.186665	0.781734	2.600562
45	1	0	0.898782	2.533977	2.638105
46	1	0	-0.374117	1.431127	2.040255
47	1	0	0.869449	2.954711	-1.137792
48	1	0	-0.557024	2.649565	-0.133594
49	1	0	-5.195715	-2.912770	1.452776
50	1	0	0.106110	-2.997940	0.199584
51	1	0	-0.777711	-4.451797	0.658027
52	1	0	-0.696211	-3.957745	-1.040247
53	1	0	-2.929713	-5.444841	0.526854
54	1	0	-2.447560	-4.860622	2.120684
55	1	0	-4.161638	-4.982276	1.708888
56	1	0	-1.920411	1.451036	-1.818780
57	1	0	-3.034688	3.596404	-2.306779
58	1	0	-5.302734	4.081685	-1.467384
59	1	0	-6.533170	2.351319	-0.123542

Free Energy and Geometry 39* (Conformer 18 of 21):



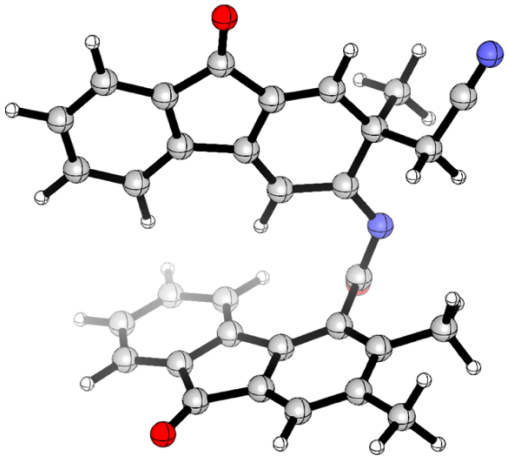
Sum of electronic and thermal free energies: -1566.810993 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-3.967644	-1.671141	2.256083
2	6	0	-4.006241	-0.801898	1.168630
3	6	0	-5.220547	-0.538339	0.514168
4	6	0	-6.410331	-1.125921	0.921781
5	6	0	-6.369086	-1.995227	2.009232
6	6	0	-5.160503	-2.262408	2.665943
7	6	0	-4.995249	0.416976	-0.609311
8	6	0	-3.527208	0.707673	-0.583075
9	6	0	-2.926818	-0.038825	0.522769
10	6	0	-1.616058	0.055152	0.831660
11	6	0	-0.760473	0.933629	0.044311
12	6	0	-1.311639	1.569253	-1.242538
13	6	0	-2.805228	1.483179	-1.392383
14	8	0	-5.817616	0.860204	-1.380543
15	6	0	-0.690088	0.779331	-2.422492
16	6	0	-0.840763	3.045207	-1.291209
17	6	0	-1.222608	3.698427	-2.545590
18	7	0	-1.540884	4.190302	-3.542038
19	7	0	0.491208	1.165501	0.263946
20	6	0	1.167127	0.700942	1.397543
21	8	0	0.682669	0.624455	2.511398
22	6	0	2.632366	0.457908	1.147128
23	6	0	3.063908	-0.502761	0.234944
24	6	0	4.433758	-0.633684	-0.023694
25	6	0	5.379019	0.137447	0.621923
26	6	0	4.962606	1.079990	1.565840
27	6	0	3.587273	1.249954	1.823986
28	6	0	3.174291	2.306413	2.819266

29	6	0	5.985947	1.916701	2.289482
30	6	0	4.641848	-1.676988	-1.072036
31	6	0	3.273791	-2.193890	-1.384453
32	6	0	2.336974	-1.520601	-0.581034
33	6	0	1.007286	-1.914190	-0.622063
34	6	0	0.633658	-2.936229	-1.504680
35	6	0	1.566528	-3.569270	-2.322764
36	6	0	2.914948	-3.205173	-2.255323
37	8	0	5.693093	-2.032900	-1.559645
38	1	0	-3.037550	-1.885101	2.773430
39	1	0	-7.337340	-0.906734	0.401334
40	1	0	-7.279876	-2.472793	2.355076
41	1	0	-5.155144	-2.943292	3.510930
42	1	0	-1.191874	-0.454863	1.688434
43	1	0	-3.268408	2.019549	-2.219761
44	1	0	-0.985357	-0.272510	-2.371169
45	1	0	-1.028026	1.192559	-3.377035
46	1	0	0.400105	0.841621	-2.356986
47	1	0	-1.269811	3.610859	-0.458376
48	1	0	0.247256	3.068611	-1.188557
49	1	0	6.434566	0.006732	0.397297
50	1	0	3.395549	1.975364	3.840782
51	1	0	3.734875	3.230322	2.652094
52	1	0	2.111082	2.536087	2.774739
53	1	0	5.904026	2.974857	2.016298
54	1	0	5.858720	1.854297	3.375217
55	1	0	6.996924	1.584323	2.044695
56	1	0	0.257676	-1.472031	0.023662
57	1	0	-0.407056	-3.243944	-1.542337
58	1	0	1.247403	-4.356766	-2.997290
59	1	0	3.669779	-3.701659	-2.857772

Free Energy and Geometry 39* (Conformer 19 of 21):



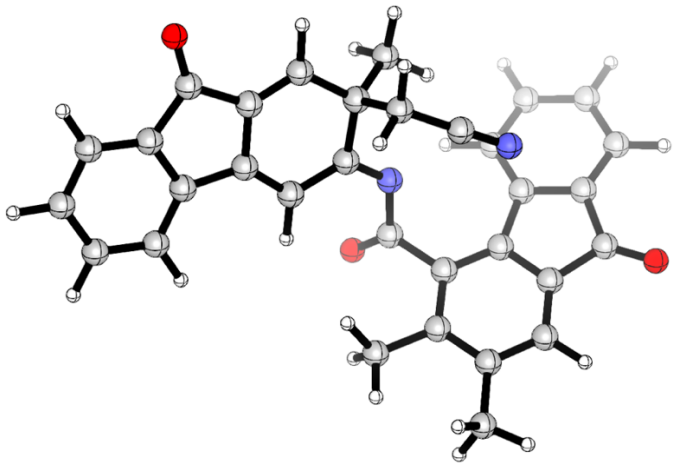
Sum of electronic and thermal free energies: -1566.812496 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	0.013986	3.307821	0.041064
2	6	0	1.208627	2.615012	0.223179
3	6	0	2.298465	3.221986	0.866519
4	6	0	2.226769	4.527339	1.335581
5	6	0	1.033876	5.222061	1.150112
6	6	0	-0.057542	4.616662	0.511523
7	6	0	3.441589	2.263828	0.945534
8	6	0	2.946949	1.010964	0.288320
9	6	0	1.568574	1.241089	-0.149443
10	6	0	0.843794	0.284667	-0.753703
11	6	0	1.412974	-1.048145	-0.934212
12	6	0	2.913309	-1.266369	-0.686732
13	6	0	3.577268	-0.144611	0.073738
14	8	0	4.533906	2.454803	1.433586
15	6	0	3.594145	-1.353973	-2.073120
16	6	0	3.082331	-2.608337	0.069313
17	6	0	4.492743	-2.954944	0.262161
18	7	0	5.612880	-3.202062	0.404487
19	7	0	0.734914	-2.058702	-1.335058
20	6	0	-0.632125	-1.971208	-1.618778
21	8	0	-1.050670	-1.908661	-2.755528
22	6	0	-1.533682	-2.009743	-0.412753
23	6	0	-2.414908	-0.952291	-0.177589
24	6	0	-3.135729	-0.939266	1.025204
25	6	0	-3.051855	-1.958902	1.950439
26	6	0	-2.221832	-3.053476	1.691400
27	6	0	-1.452608	-3.074529	0.513177

28	6	0	-0.568698	-4.270994	0.256250
29	6	0	-2.144995	-4.189564	2.677694
30	6	0	-3.907973	0.333235	1.130776
31	6	0	-3.597809	1.082207	-0.123357
32	6	0	-2.740237	0.307224	-0.925865
33	6	0	-2.370006	0.793316	-2.175923
34	6	0	-2.831254	2.057635	-2.569614
35	6	0	-3.658913	2.823659	-1.751861
36	6	0	-4.061480	2.325930	-0.508783
37	8	0	-4.625775	0.685730	2.041652
38	1	0	-0.838732	2.844756	-0.450636
39	1	0	3.079158	4.981224	1.831345
40	1	0	0.942642	6.243417	1.504779
41	1	0	-0.977129	5.178870	0.383438
42	1	0	-0.176484	0.465724	-1.072410
43	1	0	4.610142	-0.288485	0.389025
44	1	0	3.440718	-0.425287	-2.628886
45	1	0	4.669251	-1.520556	-1.960905
46	1	0	3.154149	-2.181556	-2.637148
47	1	0	2.598288	-2.556407	1.049741
48	1	0	2.593571	-3.401197	-0.504301
49	1	0	-3.628386	-1.904525	2.870435
50	1	0	-1.121495	-5.196080	0.444606
51	1	0	-0.191912	-4.302913	-0.765652
52	1	0	0.295291	-4.270845	0.931837
53	1	0	-2.545392	-5.115610	2.249899
54	1	0	-1.111449	-4.393856	2.975935
55	1	0	-2.720542	-3.958750	3.576445
56	1	0	-1.747671	0.216058	-2.848955
57	1	0	-2.538498	2.441279	-3.541999
58	1	0	-4.000698	3.797358	-2.086926
59	1	0	-4.721593	2.888033	0.145148

Free Energy and Geometry 39* (Conformer 20 of 21):



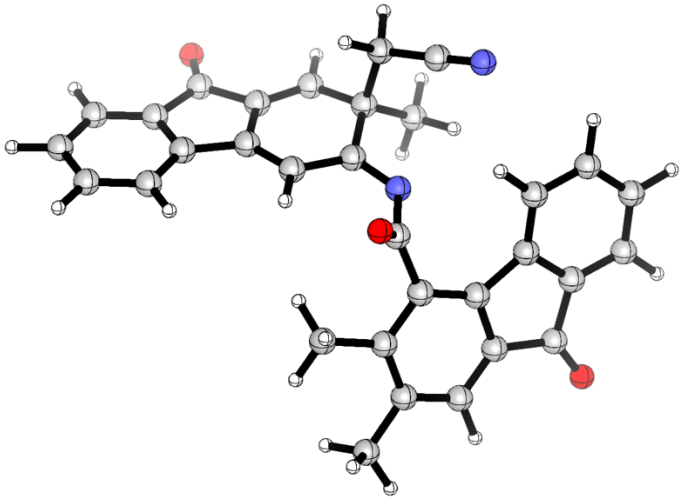
Sum of electronic and thermal free energies: -1566.809182 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	4.865919	1.951065	-0.673067
2	6	0	4.588414	0.654111	-0.248239
3	6	0	5.631553	-0.199431	0.146376
4	6	0	6.957727	0.212428	0.127236
5	6	0	7.232148	1.509457	-0.297851
6	6	0	6.195461	2.365879	-0.692468
7	6	0	5.079652	-1.522341	0.555934
8	6	0	3.597671	-1.395489	0.386375
9	6	0	3.303454	-0.053071	-0.126203
10	6	0	2.051174	0.333416	-0.432611
11	6	0	0.950609	-0.616701	-0.267397
12	6	0	1.187114	-1.947295	0.466585
13	6	0	2.644114	-2.289803	0.644064
14	8	0	5.692176	-2.491918	0.948269
15	6	0	0.454744	-3.095508	-0.241490
16	6	0	0.635132	-1.778091	1.920129
17	6	0	-0.818282	-1.585839	1.985511
18	7	0	-1.961811	-1.448320	2.083233
19	7	0	-0.260091	-0.402509	-0.632058
20	6	0	-0.690287	0.760532	-1.266514
21	8	0	-0.207478	1.201287	-2.291423
22	6	0	-1.871446	1.371566	-0.567059
23	6	0	-3.023577	0.629401	-0.323058
24	6	0	-4.057316	1.218349	0.416187
25	6	0	-3.978228	2.511519	0.887933
26	6	0	-2.838933	3.280206	0.617252
27	6	0	-1.780908	2.707188	-0.110693

28	6	0	-0.523459	3.496575	-0.392812
29	6	0	-2.774036	4.700566	1.124705
30	6	0	-5.166494	0.232090	0.584292
31	6	0	-4.726898	-0.979977	-0.169233
32	6	0	-3.460681	-0.741163	-0.729074
33	6	0	-2.889732	-1.707079	-1.547068
34	6	0	-3.583167	-2.906421	-1.752088
35	6	0	-4.825822	-3.142733	-1.166414
36	6	0	-5.417263	-2.161601	-0.366840
37	8	0	-6.204400	0.389154	1.191536
38	1	0	4.071901	2.624305	-0.981077
39	1	0	7.746875	-0.465686	0.436674
40	1	0	8.256753	1.865257	-0.325523
41	1	0	6.434763	3.372502	-1.019894
42	1	0	1.837638	1.299970	-0.875985
43	1	0	2.889783	-3.277121	1.032302
44	1	0	0.850888	-3.230702	-1.251276
45	1	0	0.593572	-4.027120	0.315873
46	1	0	-0.613413	-2.874866	-0.310360
47	1	0	0.879989	-2.673958	2.500564
48	1	0	1.121405	-0.927553	2.408940
49	1	0	-4.801229	2.929409	1.462330
50	1	0	0.362233	2.955651	-0.041589
51	1	0	-0.398107	3.655940	-1.466908
52	1	0	-0.533199	4.466385	0.102859
53	1	0	-1.950158	4.840420	1.832330
54	1	0	-2.629670	5.414969	0.308002
55	1	0	-3.701909	4.961570	1.638130
56	1	0	-1.927396	-1.554805	-2.021088
57	1	0	-3.140043	-3.667455	-2.387407
58	1	0	-5.336500	-4.083681	-1.343050
59	1	0	-6.393397	-2.306628	0.086476

Free Energy and Geometry 39* (Conformer 21 of 21):



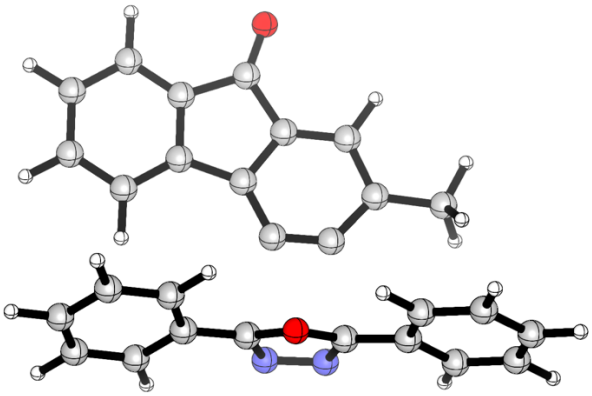
Sum of electronic and thermal free energies: -1566.810925 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-4.729653	1.782086	-0.966150
2	6	0	-4.420424	0.662847	-0.197282
3	6	0	-5.380542	0.109359	0.665419
4	6	0	-6.654789	0.649544	0.780566
5	6	0	-6.961721	1.767579	0.009709
6	6	0	-6.007602	2.324426	-0.852528
7	6	0	-4.809773	-1.072936	1.372177
8	6	0	-3.412814	-1.201807	0.849332
9	6	0	-3.171363	-0.109717	-0.100066
10	6	0	-1.971998	0.071330	-0.682864
11	6	0	-0.863534	-0.816075	-0.316597
12	6	0	-1.170623	-2.143529	0.395632
13	6	0	-2.500687	-2.138138	1.109003
14	8	0	-5.356538	-1.785076	2.186313
15	6	0	-0.045720	-2.529319	1.363429
16	6	0	-1.322844	-3.236051	-0.714594
17	6	0	-0.070827	-3.509214	-1.426942
18	7	0	0.911903	-3.753171	-1.984455
19	7	0	0.370115	-0.573927	-0.564197
20	6	0	0.809282	0.517567	-1.313588
21	8	0	0.451033	0.743340	-2.452513
22	6	0	1.826231	1.355464	-0.589374
23	6	0	2.995721	0.801198	-0.073713
24	6	0	3.879521	1.631194	0.629644
25	6	0	3.638246	2.976106	0.811800
26	6	0	2.480681	3.551096	0.272858

27	6	0	1.571118	2.738444	-0.427244
28	6	0	0.306810	3.333072	-1.002624
29	6	0	2.239711	5.029427	0.459884
30	6	0	5.045159	0.825231	1.103878
31	6	0	4.804038	-0.551982	0.580335
32	6	0	3.595685	-0.567455	-0.137819
33	6	0	3.206254	-1.732304	-0.784790
34	6	0	4.015993	-2.868524	-0.664314
35	6	0	5.199373	-2.848310	0.072317
36	6	0	5.610430	-1.669387	0.700470
37	8	0	5.985122	1.212701	1.765165
38	1	0	-3.999280	2.222909	-1.637693
39	1	0	-7.380198	0.204445	1.454362
40	1	0	-7.947739	2.215723	0.073686
41	1	0	-6.271020	3.195973	-1.443078
42	1	0	-1.778258	0.880254	-1.378261
43	1	0	-2.712943	-2.955296	1.796787
44	1	0	0.048688	-1.776540	2.149917
45	1	0	-0.269457	-3.494830	1.827064
46	1	0	0.908776	-2.594585	0.836155
47	1	0	-1.656082	-4.171906	-0.253620
48	1	0	-2.083299	-2.934021	-1.441818
49	1	0	4.350467	3.583671	1.364469
50	1	0	0.363720	3.382679	-2.093800
51	1	0	-0.564990	2.720511	-0.753741
52	1	0	0.123109	4.336541	-0.620429
53	1	0	2.114759	5.541885	-0.499105
54	1	0	1.339707	5.220918	1.053817
55	1	0	3.084557	5.487954	0.978160
56	1	0	2.296481	-1.789546	-1.368042
57	1	0	3.702926	-3.780809	-1.163217
58	1	0	5.805509	-3.745216	0.147709
59	1	0	6.537454	-1.616083	1.263731

Free Energy and Geometry for TS5:



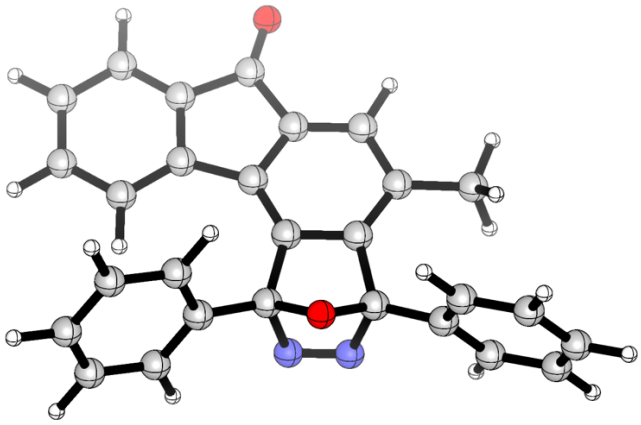
Sum of electronic and thermal free energies: -1336.840568 a.u.

Number of imaginary frequencies: -1

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	2.344794	-1.017166	-0.501760
2	6	0	0.423326	-1.899482	-0.536159
3	8	0	1.431329	-1.595824	0.312944
4	6	0	3.628767	-0.571404	0.042665
5	6	0	3.772969	-0.372321	1.418812
6	6	0	4.687129	-0.299044	-0.829410
7	6	0	4.980079	0.106768	1.920724
8	1	0	2.940878	-0.577328	2.085130
9	6	0	5.888516	0.182783	-0.319530
10	1	0	4.557125	-0.456229	-1.895283
11	6	0	6.036114	0.389196	1.053373
12	1	0	5.093741	0.265543	2.987960
13	1	0	6.710868	0.397999	-0.993789
14	1	0	6.973755	0.768299	1.446811
15	6	0	-0.775132	-2.577157	-0.038802
16	6	0	-1.164869	-2.419944	1.294867
17	6	0	-1.545294	-3.344911	-0.918117
18	6	0	-2.330509	-3.031201	1.747170
19	1	0	-0.567814	-1.806228	1.962556
20	6	0	-2.712666	-3.948920	-0.458185
21	1	0	-1.229289	-3.456270	-1.950073
22	6	0	-3.106813	-3.792303	0.871761
23	1	0	-2.639022	-2.904316	2.779487
24	1	0	-3.313767	-4.543591	-1.138073
25	1	0	-4.018762	-4.262360	1.225556
26	7	0	2.047154	-1.271433	-1.779166
27	7	0	0.844657	-1.824372	-1.800107
28	6	0	-3.473834	-0.175975	-0.298487

29	6	0	-2.690427	0.961424	-0.181098
30	6	0	-3.282205	2.205695	0.096592
31	6	0	-4.648580	2.341802	0.265861
32	6	0	-5.442609	1.192625	0.153726
33	6	0	-4.859081	-0.043934	-0.124693
34	6	0	-0.922670	2.531393	-0.096535
35	6	0	-1.227947	1.163031	-0.297730
36	6	0	1.486244	2.199017	-0.380941
37	6	0	0.372308	3.041114	-0.137408
38	6	0	-2.210794	3.254389	0.160317
39	8	0	-2.361502	4.439068	0.379476
40	6	0	2.898053	2.708934	-0.430223
41	1	0	-3.033272	-1.143419	-0.519056
42	1	0	-5.085268	3.312962	0.478665
43	1	0	-6.517642	1.263336	0.281884
44	1	0	-5.488962	-0.924308	-0.210390
45	1	0	0.534572	4.105071	0.019162
46	1	0	2.914585	3.797528	-0.348213
47	1	0	3.496104	2.289183	0.385898
48	1	0	3.379856	2.421267	-1.368759
49	6	0	1.066375	0.888224	-0.557443
50	6	0	-0.109406	0.390293	-0.538335

Free Energy and Geometry for 36:



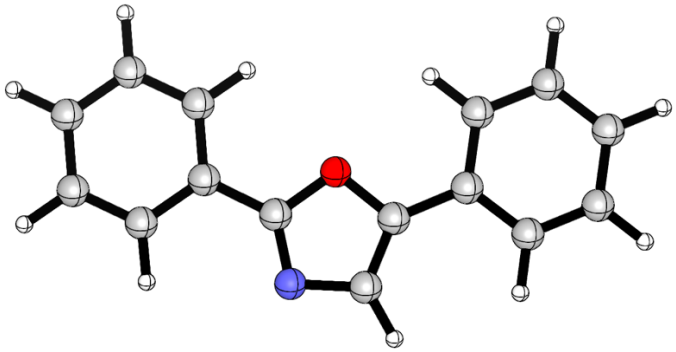
Sum of electronic and thermal free energies: -1336.926938 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	3.484644	0.313844	-0.326334
2	6	0	2.700289	-0.815095	-0.119613
3	6	0	3.328507	-2.056658	0.092436
4	6	0	4.704994	-2.198832	0.127031
5	6	0	5.489311	-1.056966	-0.063144
6	6	0	4.879215	0.176222	-0.291594
7	6	0	2.290603	-3.119532	0.230098
8	6	0	0.979298	-2.415735	0.081712
9	6	0	1.221556	-1.032537	-0.099159
10	6	0	0.099112	-0.234596	-0.194918
11	6	0	-1.186748	-0.814841	-0.181722
12	6	0	-1.426896	-2.175695	-0.059505
13	6	0	-0.278489	-2.981192	0.102880
14	8	0	2.468327	-4.306227	0.416173
15	6	0	-2.801479	-2.793837	-0.086912
16	6	0	-0.184701	1.254400	-0.379813
17	7	0	-0.715676	1.336507	-1.844320
18	7	0	-1.828279	0.828901	-1.844127
19	6	0	-2.116598	0.380767	-0.374235
20	8	0	-1.410901	1.393254	0.309665
21	6	0	0.822528	2.287521	-0.007095
22	6	0	-3.564159	0.305420	-0.024472
23	6	0	-4.524072	0.067521	-1.008588
24	6	0	-5.865061	-0.062944	-0.648666
25	6	0	-6.246522	0.049796	0.687528
26	6	0	-5.285157	0.298817	1.668397
27	6	0	-3.944298	0.425778	1.314584
28	6	0	1.285785	2.315540	1.311601

29	6	0	2.259475	3.236139	1.686138
30	6	0	2.774512	4.128426	0.743172
31	6	0	2.302163	4.107597	-0.568075
32	6	0	1.320448	3.190467	-0.946517
33	1	0	3.049842	1.286789	-0.517883
34	1	0	5.150718	-3.174920	0.293107
35	1	0	6.571509	-1.129228	-0.041748
36	1	0	5.495660	1.055657	-0.450246
37	1	0	-0.379485	-4.055123	0.238180
38	1	0	-2.729498	-3.874112	0.052725
39	1	0	-3.441832	-2.383900	0.699322
40	1	0	-3.299260	-2.604662	-1.042279
41	1	0	-4.222384	-0.020670	-2.047183
42	1	0	-6.611116	-0.250304	-1.414145
43	1	0	-7.290865	-0.052379	0.964734
44	1	0	-5.579574	0.392224	2.708714
45	1	0	-3.188862	0.613685	2.071767
46	1	0	0.893508	1.604488	2.033736
47	1	0	2.623821	3.252296	2.708053
48	1	0	3.541294	4.839957	1.032568
49	1	0	2.697295	4.804248	-1.300250
50	1	0	0.957945	3.163108	-1.968049

Free Energy and Geometry for 2,5-diphenyloxazole (34):

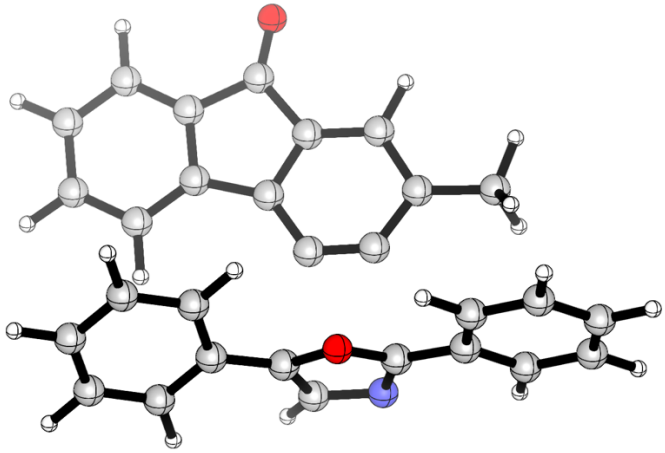


Sum of electronic and thermal free energies: -707.766550 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	7	0	-0.767056	-1.996369	-0.001615
2	6	0	0.614359	-2.019883	-0.001585
3	6	0	1.090104	-0.742546	-0.000542
4	8	0	0.000129	0.082201	0.000105
5	6	0	-1.078348	-0.734306	-0.000481
6	6	0	-2.409587	-0.128093	0.000062
7	6	0	2.417514	-0.138086	-0.000128
8	6	0	-2.565995	1.262627	0.001591
9	6	0	-3.844125	1.815490	0.002063
10	6	0	-4.967080	0.988044	0.001040
11	6	0	-4.809679	-0.399413	-0.000468
12	6	0	-3.536571	-0.959226	-0.000971
13	6	0	2.572427	1.253984	-0.003131
14	6	0	3.847525	1.814813	-0.002889
15	6	0	4.976889	0.997205	0.000273
16	6	0	4.825396	-0.390996	0.003303
17	6	0	3.555674	-0.957306	0.003219
18	1	0	1.168256	-2.947684	-0.002542
19	1	0	-1.690345	1.904685	0.002409
20	1	0	-3.962703	2.894994	0.003248
21	1	0	-5.962513	1.422476	0.001418
22	1	0	-5.681880	-1.046500	-0.001259
23	1	0	-3.400825	-2.036569	-0.002155
24	1	0	1.694237	1.892396	-0.005706
25	1	0	3.957549	2.895371	-0.005242
26	1	0	5.969667	1.437244	0.000415
27	1	0	5.700141	-1.034734	0.005875
28	1	0	3.445753	-2.038558	0.005870

Free Energy and Geometry for TS6a:



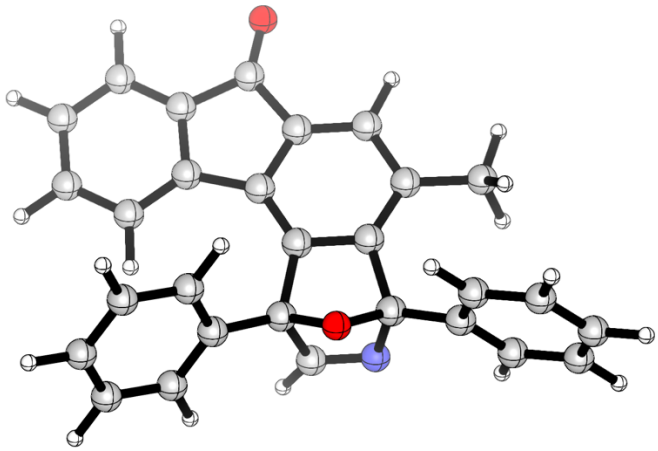
Sum of electronic and thermal free energies: -1320.809534 a.u.

Number of imaginary frequencies: -1

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	2.397330	-1.060230	-0.602268
2	6	0	0.444744	-1.971935	-0.559429
3	8	0	1.478829	-1.605718	0.235430
4	6	0	3.664370	-0.587661	-0.036822
5	6	0	3.825835	-0.475052	1.347993
6	6	0	4.695576	-0.201666	-0.898975
7	6	0	5.016144	0.029242	1.865447
8	1	0	3.018507	-0.768505	2.011303
9	6	0	5.880548	0.304851	-0.374498
10	1	0	4.553272	-0.290531	-1.971156
11	6	0	6.042891	0.424520	1.006972
12	1	0	5.139755	0.118813	2.939817
13	1	0	6.678428	0.608640	-1.044402
14	1	0	6.967101	0.822911	1.413067
15	6	0	-0.747079	-2.565053	0.045634
16	6	0	-1.141174	-2.193369	1.336837
17	6	0	-1.525798	-3.467490	-0.688214
18	6	0	-2.309494	-2.715353	1.883049
19	1	0	-0.542688	-1.478145	1.893284
20	6	0	-2.699953	-3.978381	-0.139815
21	1	0	-1.211959	-3.771081	-1.682576
22	6	0	-3.094296	-3.602995	1.144806
23	1	0	-2.616654	-2.417317	2.880172
24	1	0	-3.302264	-4.675379	-0.713352

25	1	0	-4.009801	-4.001303	1.570114
26	7	0	2.121108	-1.299785	-1.877306
27	6	0	-3.444932	-0.226691	-0.523930
28	6	0	-2.695955	0.919575	-0.309525
29	6	0	-3.327057	2.127555	0.033553
30	6	0	-4.700834	2.219069	0.168122
31	6	0	-5.461206	1.061263	-0.045979
32	6	0	-4.837860	-0.140110	-0.385590
33	6	0	-0.969552	2.516658	-0.044534
34	6	0	-1.236691	1.161381	-0.360147
35	6	0	1.455713	2.244156	-0.244781
36	6	0	0.317201	3.048808	0.010575
37	6	0	-2.282436	3.191658	0.212456
38	8	0	-2.472462	4.354072	0.508883
39	6	0	2.859258	2.777351	-0.189743
40	1	0	-2.970637	-1.168332	-0.785111
41	1	0	-5.169066	3.162139	0.433734
42	1	0	-6.541011	1.097415	0.053481
43	1	0	-5.441926	-1.028281	-0.545156
44	1	0	0.451563	4.099224	0.259206
45	1	0	2.858844	3.843678	0.045989
46	1	0	3.448365	2.250925	0.568816
47	1	0	3.364153	2.632124	-1.149221
48	6	0	1.078581	0.939781	-0.541775
49	6	0	-0.089033	0.438526	-0.609118
50	6	0	0.897012	-1.857213	-1.869639
51	1	0	0.356209	-2.092528	-2.775342

Free Energy and Geometry for 37:



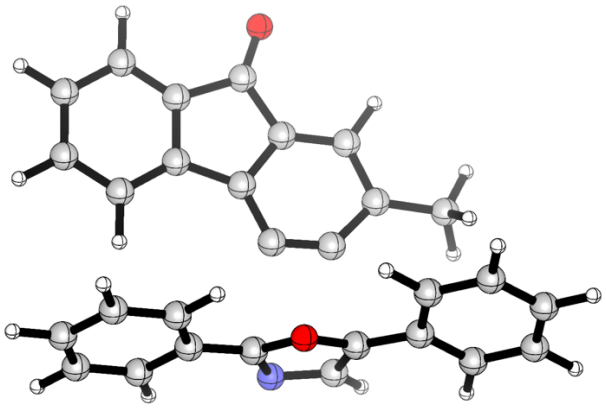
Sum of electronic and thermal free energies: -1320.895613 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	3.480117	0.308996	-0.402749
2	6	0	2.690449	-0.808983	-0.157261
3	6	0	3.314146	-2.046377	0.089397
4	6	0	4.690250	-2.193521	0.123866
5	6	0	5.479368	-1.061865	-0.103561
6	6	0	4.874089	0.166504	-0.368831
7	6	0	2.271778	-3.102196	0.254487
8	6	0	0.964621	-2.399751	0.083595
9	6	0	1.210648	-1.019589	-0.132296
10	6	0	0.095980	-0.218973	-0.261230
11	6	0	-1.193164	-0.793645	-0.248704
12	6	0	-1.437872	-2.147726	-0.090685
13	6	0	-0.294744	-2.957493	0.106155
14	8	0	2.449170	-4.284042	0.473250
15	6	0	-2.814002	-2.763636	-0.129240
16	6	0	-0.173864	1.286104	-0.479038
17	6	0	-0.763711	1.331985	-1.908094
18	7	0	-1.920099	0.804699	-1.917664
19	6	0	-2.131428	0.408972	-0.483582
20	8	0	-1.416336	1.414440	0.234080
21	6	0	0.838695	2.281622	-0.010835
22	6	0	-3.560758	0.314918	-0.049264
23	6	0	1.302633	2.183672	1.305033
24	6	0	2.270990	3.065320	1.773339
25	6	0	2.786501	4.049357	0.926613
26	6	0	2.314790	4.159663	-0.379862
27	6	0	1.335231	3.281544	-0.846930

28	6	0	-3.850596	0.318532	1.317967
29	6	0	-5.166306	0.177689	1.750943
30	6	0	-6.196254	0.029369	0.819883
31	6	0	-5.906094	0.033052	-0.543484
32	6	0	-4.589294	0.179703	-0.980634
33	1	0	3.048544	1.278100	-0.621528
34	1	0	5.132108	-3.166450	0.317068
35	1	0	6.561345	-1.138483	-0.083390
36	1	0	5.494241	1.037628	-0.556703
37	1	0	-0.403892	-4.027992	0.262052
38	1	0	-2.740053	-3.851543	-0.073414
39	1	0	-3.432903	-2.415835	0.703324
40	1	0	-3.337536	-2.501335	-1.052666
41	1	0	-0.259128	1.679176	-2.804965
42	1	0	0.911536	1.402380	1.951446
43	1	0	2.632527	2.979883	2.792903
44	1	0	3.550577	4.730541	1.287313
45	1	0	2.705242	4.929263	-1.037745
46	1	0	0.974311	3.378177	-1.865778
47	1	0	-3.042524	0.427480	2.035780
48	1	0	-5.388658	0.181299	2.813285
49	1	0	-7.221450	-0.084802	1.157773
50	1	0	-6.705087	-0.075786	-1.270063
51	1	0	-4.354370	0.182737	-2.039677

Free Energy and Geometry for TS6b:



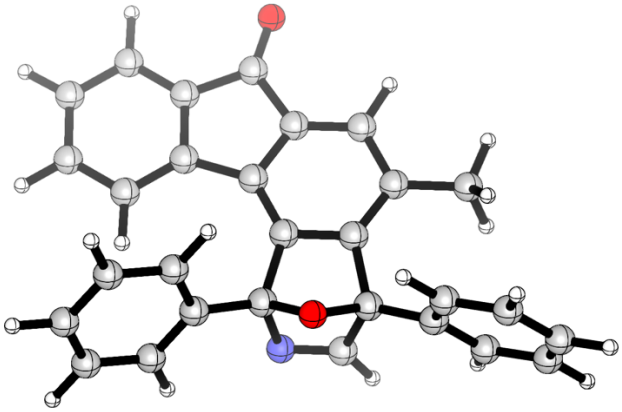
Sum of electronic and thermal free energies: -1320.810507 a.u.

Number of imaginary frequencies: -1

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	2.400456	-1.096829	-0.507365
2	6	0	0.466759	-2.041338	-0.641064
3	8	0	1.426883	-1.672389	0.242019
4	6	0	3.588019	-0.569405	0.163776
5	6	0	3.517486	-0.176390	1.505505
6	6	0	4.781818	-0.407181	-0.548198
7	6	0	4.631808	0.382922	2.124272
8	1	0	2.585119	-0.292701	2.049469
9	6	0	5.889504	0.161970	0.073136
10	1	0	4.844535	-0.723204	-1.585332
11	6	0	5.817217	0.559625	1.408862
12	1	0	4.571777	0.690587	3.163124
13	1	0	6.811783	0.289677	-0.484105
14	1	0	6.682341	1.002796	1.891300
15	6	0	-0.741424	-2.697209	-0.134335
16	6	0	-1.056265	-2.654688	1.228116
17	6	0	-1.602595	-3.331517	-1.035870
18	6	0	-2.231470	-3.245070	1.684232
19	1	0	-0.391472	-2.146178	1.919115
20	6	0	-2.778037	-3.916596	-0.572497
21	1	0	-1.347640	-3.351325	-2.090313
22	6	0	-3.095468	-3.874254	0.786330
23	1	0	-2.477774	-3.205750	2.740265
24	1	0	-3.447326	-4.405400	-1.273040
25	1	0	-4.013802	-4.328646	1.144246
26	7	0	0.876957	-1.970931	-1.896500
27	6	0	-3.466502	-0.107137	-0.041938
28	6	0	-2.671475	1.027490	-0.075972

29	6	0	-3.229754	2.297882	0.144127
30	6	0	-4.579379	2.464184	0.400341
31	6	0	-5.387203	1.319271	0.437091
32	6	0	-4.834598	0.056022	0.219271
33	6	0	-0.884445	2.566499	-0.234113
34	6	0	-1.220052	1.193965	-0.311922
35	6	0	1.489990	2.150270	-0.655520
36	6	0	0.415722	3.039786	-0.399942
37	6	0	-2.142077	3.330259	0.052220
38	8	0	-2.265457	4.531254	0.186811
39	6	0	2.910919	2.607085	-0.822476
40	1	0	-3.043782	-1.093869	-0.211130
41	1	0	-4.994015	3.453819	0.567817
42	1	0	-6.449605	1.413768	0.636105
43	1	0	-5.476139	-0.819605	0.252091
44	1	0	0.614595	4.106961	-0.331567
45	1	0	2.955474	3.692957	-0.928796
46	1	0	3.517848	2.317827	0.043041
47	1	0	3.364371	2.149787	-1.706300
48	6	0	1.018688	0.848301	-0.707915
49	6	0	-0.150454	0.357464	-0.576004
50	6	0	2.079688	-1.366897	-1.834489
51	1	0	2.642338	-1.096820	-2.717089

Free Energy and Geometry for 38:



Sum of electronic and thermal free energies: -1320.895326 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	5.470467	-1.082549	-0.052722
2	6	0	4.871332	0.148605	-0.319490
3	6	0	3.478365	0.295096	-0.371018
4	6	0	2.683057	-0.822070	-0.141865
5	6	0	3.300494	-2.061881	0.108582
6	6	0	4.675779	-2.213013	0.159820
7	6	0	2.254126	-3.114390	0.261700
8	6	0	0.950585	-2.407061	0.081407
9	6	0	1.202051	-1.027829	-0.133252
10	6	0	0.090948	-0.224897	-0.274318
11	6	0	-1.201129	-0.794588	-0.261000
12	6	0	-1.450950	-2.147423	-0.091310
13	6	0	-0.310360	-2.960154	0.105646
14	8	0	2.424395	-4.297527	0.479863
15	6	0	-2.828752	-2.761639	-0.100568
16	6	0	-0.173190	1.279882	-0.488288
17	7	0	-0.614480	1.410951	-1.916837
18	6	0	-2.135777	0.416020	-0.483716
19	8	0	-1.399207	1.416483	0.235973
20	6	0	0.844675	2.274929	-0.030487
21	6	0	-3.566042	0.327206	-0.051685
22	6	0	1.269695	2.228070	1.300359
23	6	0	2.246455	3.110607	1.750931
24	6	0	2.802725	4.042937	0.872156
25	6	0	2.367005	4.099193	-0.450811
26	6	0	1.383213	3.218678	-0.904015
27	6	0	-3.876953	0.489285	1.301150
28	6	0	-5.192500	0.349927	1.736371

29	6	0	-6.204019	0.045987	0.823924
30	6	0	-5.895936	-0.109424	-0.526569
31	6	0	-4.580005	0.034762	-0.964719
32	6	0	-1.777720	0.900224	-1.909552
33	1	0	6.551940	-1.161986	-0.019277
34	1	0	5.495751	1.019243	-0.495300
35	1	0	3.051582	1.265530	-0.591589
36	1	0	5.112445	-3.187890	0.355157
37	1	0	-0.423685	-4.028734	0.271152
38	1	0	-2.757958	-3.841063	0.047460
39	1	0	-3.459658	-2.344875	0.689934
40	1	0	-3.338775	-2.580914	-1.050996
41	1	0	0.844604	1.487872	1.973172
42	1	0	2.581357	3.066323	2.782231
43	1	0	3.572063	4.724931	1.220377
44	1	0	2.793485	4.827120	-1.133638
45	1	0	1.046653	3.245812	-1.934484
46	1	0	-3.083539	0.720712	2.005198
47	1	0	-5.428267	0.476336	2.788208
48	1	0	-7.228414	-0.065917	1.164475
49	1	0	-6.678645	-0.341879	-1.241461
50	1	0	-4.350800	-0.102163	-2.017525
51	1	0	-2.386113	0.786301	-2.801882

IV. X-ray Diffraction Data for 26 and 39

Data for 26 **CCDC Deposition # 2341587**

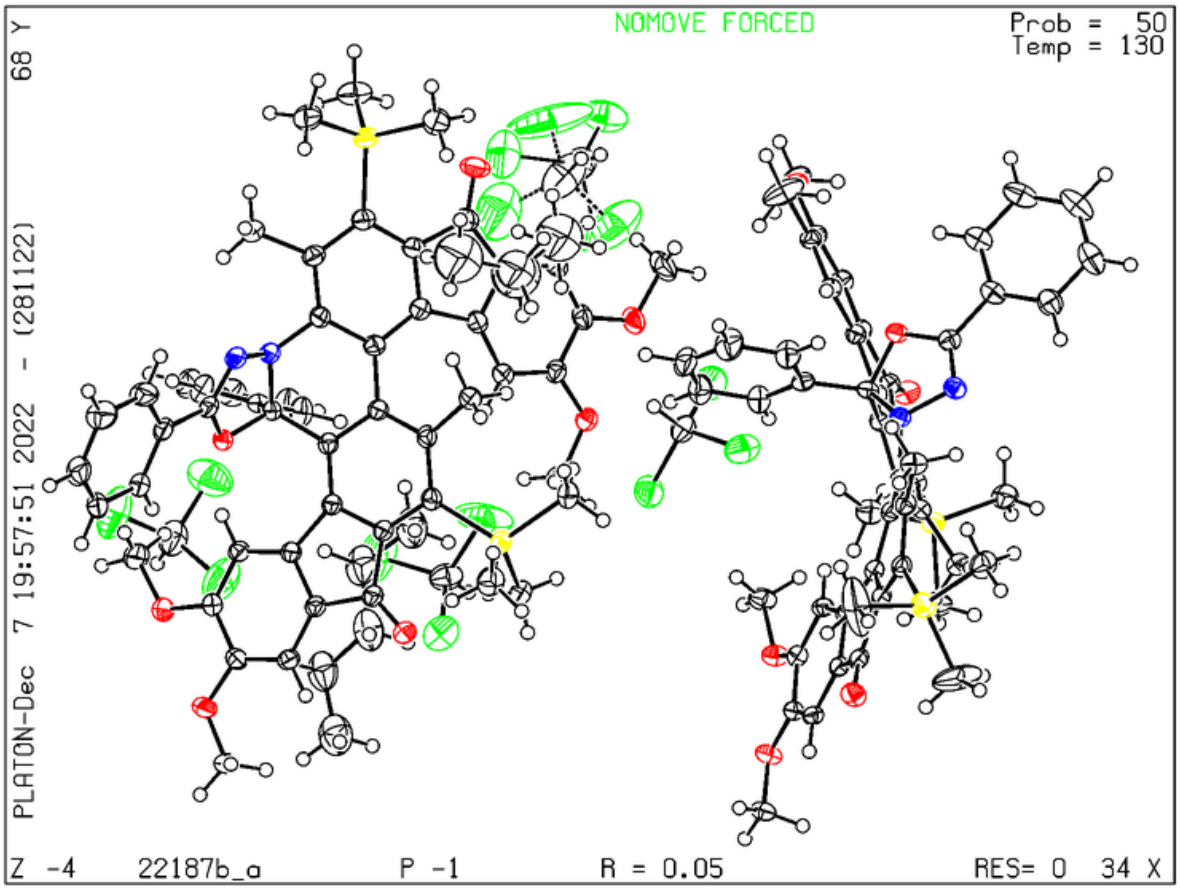
Data collection

A crystal (approximate dimensions 0.190 x 0.150 x 0.030 mm) was placed onto the tip of a 0.5 mm MiTeGen loop and mounted on a Bruker Photon-III CMOS diffractometer for a data collection at 130(2) K.[11] A preliminary set of cell constants was calculated from reflections harvested from two sets of frames. These initial sets of frames were oriented such that orthogonal wedges of reciprocal space were surveyed. This produced initial orientation matrices determined from 268 reflections. The data collection was carried out using MoKα radiation (graphite monochromator) with a frame time of 80 seconds and a detector distance of 5.0 cm. A strategy program was used to assure complete coverage of all unique data to a resolution of 0.83 Å. All major sections of frames were collected with 1.2° steps in ω or ϕ at different detector positions in 2θ. The intensity data were corrected for absorption and decay (SADABS).[12] Final cell constants were calculated from the xyz centroids of 2774 strong reflections from the actual data collection after integration (SAINT).[13] Please refer to Table S1 for additional crystal and refinement information.

Structure solution and refinement

The structure was solved using SHELXT 2018/2 (Sheldrick, 2018)[14] and refined using SHELXL-2018/3 (Sheldrick, 2018).[15] The space group P-1 was determined based on systematic absences and intensity statistics. A direct-methods solution was calculated which provided most non-hydrogen atoms from the E-map. Full-matrix least squares / difference Fourier cycles were performed which located the remaining non-hydrogen atoms. All non-hydrogen atoms were refined with anisotropic displacement parameters. All hydrogen atoms were placed in ideal positions and refined as riding atoms with relative isotropic displacement parameters. The final full matrix least squares refinement converged to $R1 = 0.0519$ and $wR2 = 0.1489$ (F^2, all data).

Data collection and structure solution were conducted at the X-Ray Crystallographic Laboratory, K193 Kolthoff Hall, Department of Chemistry, University of Minnesota. All calculations were performed using Pentium computers using the current SHELXTL suite of programs.



Ellipsoid contour probability level = 50% (hydrogen atom spheres with fixed 0.15 Å radii)

Table S1. Crystal data and structure refinement for 22187 (**26**).

Identification code	22187	
Empirical formula	$C_{115.5}H_{122}Cl_{12}N_4O_{14}Si_4$	
Formula weight	2328.0327	
Temperature	130(2) K	
Wavelength	0.71073 Å	
Crystal system	Triclinic	
Space group	P-1	
Unit cell dimensions	a = 14.8038(14) Å	α = 110.017(2)°
	b = 21.0646(15) Å	β = 106.008(2)°
	c = 22.3197(18) Å	γ = 103.447(2)°
Volume	5859.7(8) Å^3	

Z	2
Density (calculated)	1.319 Mg/m^3
Absorption coefficient	0.386 mm^{-1}
$F(000)$	2430
Crystal color, morphology	yellow, plate
Crystal size	0.190 x 0.150 x 0.030 mm^3
Theta range for data collection	1.828 to 25.350°
Index ranges	$-17 \le h \le 17$, $-24 \le k \le 25$, $-26 \le l \le 26$
Reflections collected	108324
Independent reflections	21445 [R(int) = 0.0376]
Observed reflections	16604
Completeness to theta = 25.242°	99.9%
Absorption correction	multi scan
Max. and min. transmission	0.7456 and 0.6902
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	21445 / 274 / 1409
Goodness-of-fit on F^2	1.032
Final R indices [I>2sigma(I)]	$R1$ = 0.0519, $wR2$ = 0.1338
R indices (all data)	$R1$ = 0.0706, $wR2$ = 0.1489
Extinction coefficient	n/a
Largest diff. peak and hole	1.803 and -0.995 $e.Å^{-3}$

Data for 39

Data collection **CCDC Deposition # 2341588**

A crystal (approximate dimensions 0.090 x 0.090 x 0.040 mm) was placed onto the tip of a 0.5 mm MiTeGen loop and mounted on a Bruker Photon-III CPAD diffractometer for data collection at 130(2) K.[16] A preliminary set of cell constants was calculated from reflections harvested from three sets of frames. These initial sets of frames were oriented such that orthogonal wedges of reciprocal space were surveyed. This produced initial orientation matrices determined from 151 reflections. The data collection was carried out using MoKα radiation (graphite monochromator) with a frame time of 30 seconds and a detector distance of 5.0 cm. A strategy program was used to assure complete coverage of all unique data to a resolution of 0.77 Å. All major sections of frames were collected with 1.2° steps in ω or ϕ at different detector positions in 2θ. The intensity data were corrected for absorption and decay (SADABS).[12] Final cell constants were calculated from the xyz centroids of 9842 strong reflections from the actual data collection after integration (SAINT).[13] Please refer to Table S2 for additional crystal and refinement information.

Structure solution and refinement

The structure was solved using Bruker SHELXTL[14] and refined using SHELXL-2019/1 (Sheldrick, 2019).[15] The space group P-1 was determined based on systematic absences and intensity statistics. A direct-methods solution was calculated which provided most non-hydrogen atoms from the E-map. Full-matrix least squares / difference Fourier cycles were performed which located the remaining non-hydrogen atoms. All non-hydrogen atoms were refined with anisotropic displacement parameters. All hydrogen atoms were placed in ideal positions and refined as riding atoms with relative isotropic displacement parameters. The final full matrix least squares refinement converged to $R1 = 0.0430$ and $wR2 = 0.1172$ (F^2, all data).

Data collection and structure solution were conducted at the X-Ray Crystallographic Laboratory, K193 Kolthoff Hall, Department of Chemistry, University of Minnesota. All calculations were performed using Pentium computers using the current SHELXTL suite of programs.

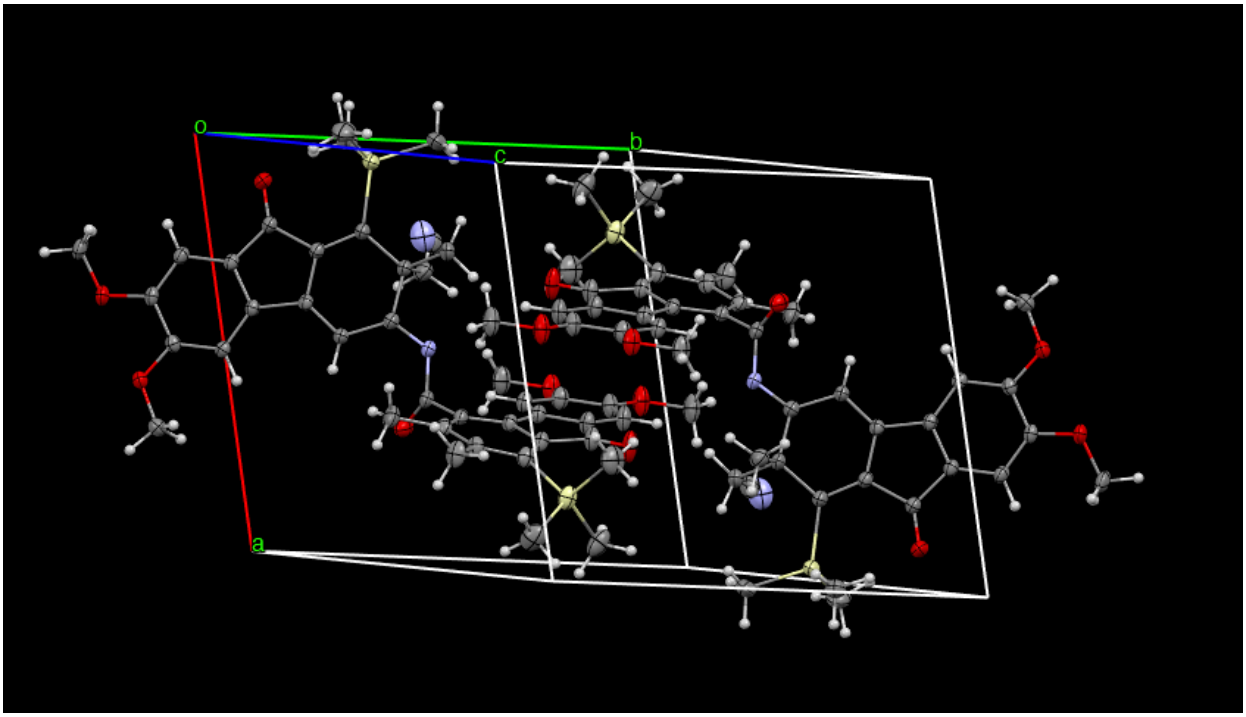


Figure S2. An image showing the packed unit cell of PK2238. Only the majorly occupied parts of the molecule are shown. Solvent has been removed for clarity.
Ellipsoid contour probability level = 50% (hydrogen atom spheres with fixed 0.15 Å radii).

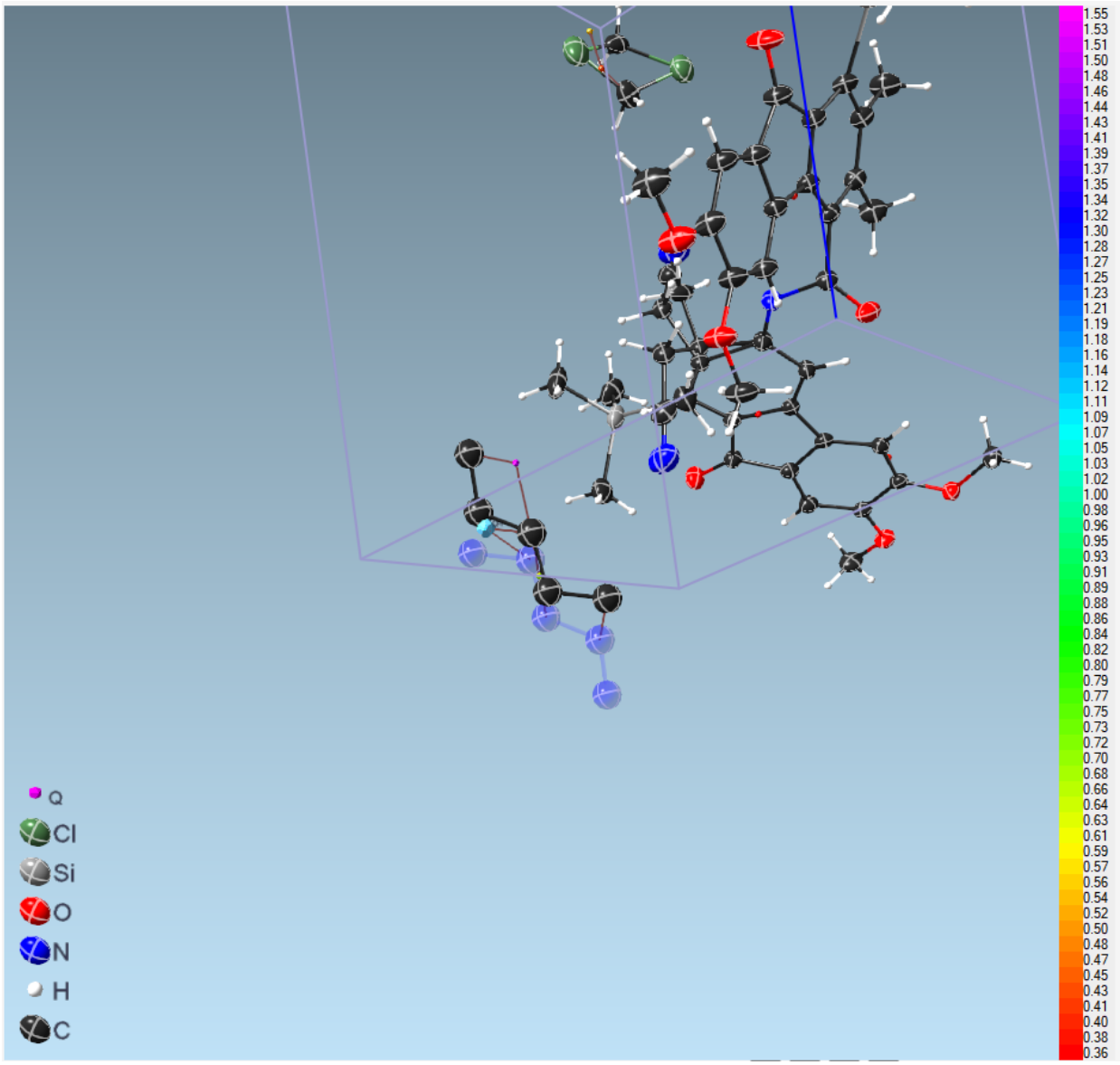


Figure S3. An image showing the initial construction of an *n*-pentane molecule disordered over the inversion center.
Ellipsoid contour probability level = 50% (hydrogen atom spheres with fixed 0.15 Å radii).

Table S2. Crystal data and structure refinement for PK2238 (**39**).

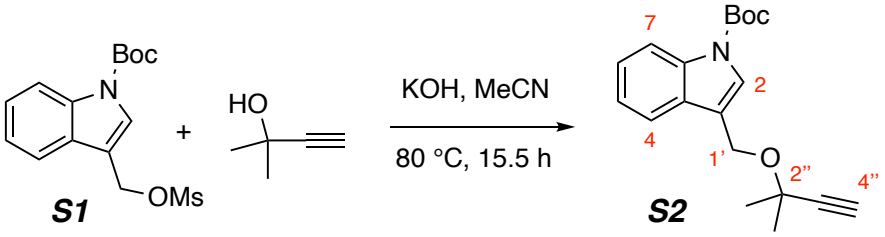
Identification code	23049e_a_sq
Empirical formula	$C_{43}H_{48}Cl_2N_2O_7Si_2$
Formula weight	831.91
Temperature	130(2) K

Wavelength	0.71073 Å	
Crystal system	Triclinic	
Space group	P-1	
Unit cell dimensions	a = 11.6550(15) Å	α = 84.046(3)°
	b = 13.5046(15) Å	β = 76.695(3)°
	c = 14.8070(19) Å	γ = 84.568(3)°
Volume	2249.7(5) Å^3	
Z	2	
Density (calculated)	1.228 Mg/m^3	
Absorption coefficient	0.246 mm^{-1}	
F(000)	876	
Crystal color, morphology	yellow, plate	
Crystal size	0.090 x 0.090 x 0.040 mm^3	
Theta range for data collection	1.990 to 27.549°	
Index ranges	$-15 \le h \le 15$, $-16 \le k \le 17$, $-19 \le l \le 19$	
Reflections collected	65383	
Independent reflections	10358 [R(int) = 0.0456]	
Observed reflections	7977	
Completeness to theta = 25.242°	99.9%	
Absorption correction	multi-scan	
Max. and min. transmission	0.7456 and 0.7091	
Refinement method	Full-matrix least-squares on F^2	
Data / restraints / parameters	10358 / 7 / 575	
Goodness-of-fit on F^2	1.034	
Final R indices [I>2sigma(I)]	R1 = 0.0430, wR2 = 0.1064	
R indices (all data)	R1 = 0.0610, wR2 = 0.1172	
Extinction coefficient	n/a	
Largest diff. peak and hole	0.463 and -0.730 e.Å^{-3}	

Supplementary Information for Chapter III

I. Experimental Procedures and Characterization Data for New Compounds

tert-Butyl 3-(((2-Methylbut-3-yn-2-yl)oxy)methyl)-1*H*-indole-1-carboxylate (S2)



To a threaded culture tube equipped with a magnetic stir bar was added *tert*-butyl 3-(((methylsulfonyl)oxy)methyl)-1*H*-indole-1-carboxylate[17] (**S1**, 513 mg, 1.6 mmol, 1 equiv), 2-methylbut-3-yn-2-ol (0.23 mL, 2.4 mmol, 1.5 equiv), and MeCN (7 mL). Solid KOH (174 mg, 3.1 mmol, 2 equiv) was added, and the culture tube was sealed with a Teflon-lined screw cap. The suspension was heated at 80 °C and stirred for 15.5 h. The reaction was quenched with H_2O, and the crude product was extracted with EtOAc. The organic layer was washed with brine, dried with $MgSO_4$, and concentrated under vacuum. The resulting residue was purified by flash column chromatography (9:1 hex:EtOAc) to afford **S2** (192 mg, 39%) as a yellow oil.

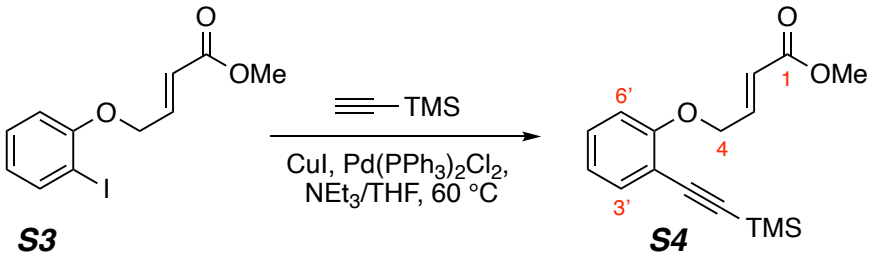
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.12 (two broad singlets, J = 7.3 Hz, 1H, *H2*), 7.67 (ddd, J = 7.8, 1.3, 0.8 Hz, 1H, *H4*), 7.59 (broad m, 1H, *H7*), 7.31 (ddd, J = 8.4, 7.2, 1.4 Hz, 1H, *H6*), 7.26–7.22 (nfom, 1H, *H5*), 4.78 (d, J =1.1 Hz, 2H, *H1'*), 2.55 (s, 1H, *H4"*), 1.65 (s, 9H, N-Boc), and 1.59 [s, 6H, C2"(CH_3)$_2$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 149.9, 135.9, 129.9, 124.6, 124.5, 122.7, 119.8, 118.2, 115.4, 86.1, 83.7, 72.7, 70.6, 58.6, 29.0, and 28.3.

IR (neat): 3294, 2982, 2935, 2868, 1731, 1452, 1352, 1257, 1154, and 1089 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{19}H_{24}NO_3^+$, 314.1751; found, 314.1752.

Methyl (*E*)-4-(2-((Trimethylsilyl)ethynyl)phenoxy)but-2-enoate (S4)



S3 ***S4***

To a solution of methyl (*E*)-4-(2-iodophenoxy)but-2-enoate[18] (**S3**, 917 mg, 2.9 mmol, 1.0 equiv) and trimethylsilylacetylene (0.8 mL, 5.8 mmol, 2.0 equiv) in Et_3N (8 mL) and THF (4 mL) was added $Pd(PPh_3)_2Cl_2$ (40 mg, 0.057 mmol, 0.02 equiv) and CuI (22 mg, 0.12 mmol, 0.04 equiv). The reaction vessel was purged with N_2 and the solution was stirred at 60 °C for 3 h. The reaction mixture was passed through a silica plug (EtOAc elution) and concentrated under vacuum. The residue was purified by flash column chromatography (9:1 → 6:1 hex:EtOAc) to afford **S4** (263 mg, 32%) as a clear light-yellow oil.

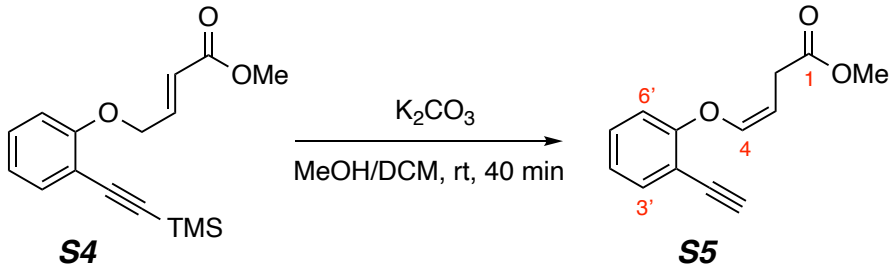
^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.45 (dd, *J* = 7.6, 1.7 Hz, 1H, *H3'*), 7.26 (ddd, *J* = 8.4, 7.5, 1.8 Hz, 1H, *H5'*), 7.10 (dt, *J* = 15.7, 3.5 Hz, 1H, *H3*), 6.92 (ddd, *J* = 7.6, 7.6, 1.0 Hz, 1H, *H4'*), 6.80 (dd, *J* = 8.4, 1.1 Hz, 1H, *H6'*), 6.45 (dt, *J* = 15.6, 2.2 Hz, 1H, *H2*), 4.73 (dd, *J* = 3.6, 2.2 Hz, 2H, *H4*), 3.76 (s, 3H, CO_2CH_3), and 0.28 [s, 9H, $Si(CH_3)_3$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 166.8, 159.0, 142.3, 134.0, 130.0, 121.5, 121.2, 113.5, 113.2, 100.9, 99.2, 66.9, 51.7, and 0.1.

IR (neat): 3074, 3028, 2994, 2955, 2899, 2849, 2157, 1724, 1490, 1440, 1309, 1278, 1250, and 1172 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{16}H_{21}O_3Si^+$, 289.1254; found, 289.1271.

Methyl (*Z*)-4-(2-Ethynylphenoxy)but-3-enoate (S5)



S4 ***S5***

To a solution of **S4** (200 mg, 0.69 mmol, 1.0 equiv), MeOH (10 mL), and DCM (5 mL) was added K_2CO_3 (300 mg, 2.2 mmol, 3.1 equiv). The suspension was stirred at room temperature for 40 min. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified by flash column chromatography (6:1 hex:EtOAc) to afford **S5** (114 mg, 76%) as a clear light-yellow oil.

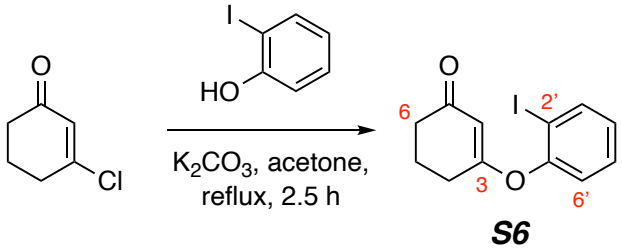
^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.48 (dd, *J* = 7.6, 1.7 Hz, 1H, *H3'*), 7.31 (ddd, *J* = 8.3, 7.4, 1.7 Hz, 1H, *H5'*), 7.02 (ddd, *J* = 7.5, 7.5, 1.1 Hz, 1H, *H4'*), 6.97 (dd, *J* = 8.3, 1.2 Hz, 1H, *H6'*), 6.53 (dt, *J* = 6.0, 1.7 Hz, 1H, *H4*), 5.12 (td, *J* = 7.1, 5.9 Hz, 1H, *H3*), 3.71 (s, 3H, CO_2CH_3), 3.36 (dd, *J* = 7.0, 1.7 Hz, 2H, *H2*), and 3.28 (s, 1H, C≡C-H).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 172.3, 158.1, 142.2, 134.3, 130.3, 122.9, 115.3, 112.7, 105.1, 82.0, 79.2, 52.0, and 29.7.

IR (neat): 3284, 3075, 3061, 3029, 3000, 2952, 1736, 1672, 1574, 1486, 1445, 1332, 1252, 1197, 1170, 1114, and 1019 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{13}H_{13}O_3^+$, 217.0859; found, 217.0873.

3-(2-Iodophenoxy)cyclohex-2-en-1-one (S6)



S6

To a solution of 3-chlorocyclohex-2-en-1-one[19] (520 mg, 4.0 mmol, 1.1 equiv) in acetone (3 mL) at room temperature, was added 2-iodophenol (792 mg, 3.6 mmol, 1.0 equiv) and K_2CO_3 (1.03 g, 7.5 mmol, 2.1 equiv). The resulting suspension was then refluxed for 2.5 h. Upon completion, the crude reaction mixture was passed through a silica plug (EtOAc elution) and further purified by flash column chromatography (2.3:1 hex:EtOAc) to afford **S6** (979 mg, 87%) as a clear colorless oil.

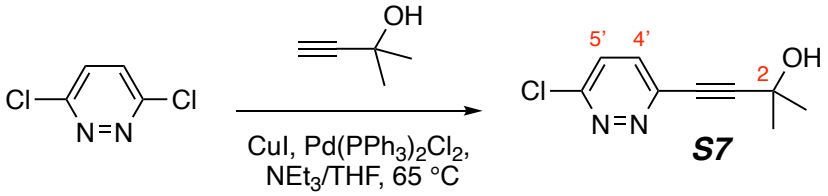
^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.84 (dd, *J* = 7.9, 1.5 Hz, 1H, *H3'*), 7.37 (ddd, *J* = 8.1, 7.4, 1.5 Hz, 1H, *H5'*), 7.08 (dd, *J* = 8.1, 1.5 Hz, 1H, *H6'*), 6.99 (ddd, *J* = 8.0, 7.4, 1.5 Hz, 1H, *H4'*), 4.98 (t, *J* = 1.0 Hz, 1H, *H2*), 2.72 (td, *J* = 6.3, 1.0 Hz, 2H, *H6*), 2.40 (nfot, J_{app} = 6.6 Hz, 2H, *H4*), and 2.11 (nfo-quintet, J_{app} = 6.5 Hz, 2H, *H5*).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 199.6, 177.0, 152.9, 140.3, 130.1, 128.0, 122.8, 106.6, 90.1, 36.8, 28.5, and 21.3.

IR (neat): 3062, 2949, 2890, 2970, 1652, 1615, 1463, 1373, 1211, 1158, and 1133 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{12}H_{11}IO_2^+$, 314.9876; found, 314.9899.

4-(6-Chloropyridazin-3-yl)-2-methylbut-3-yn-2-ol (S7)



To a solution of 3,6-dichloropyridazine (902 mg, 6.1 mmol, 2 equiv) and 2-methylbut-3-yn-2-ol (0.3 mL, 3.1 mmol, 1 equiv) in Et_3N (5 mL) and THF (5 mL) was added $Pd(PPh_3)_2Cl_2$ (85 mg, 0.12 mmol, 0.04 equiv) and CuI (46 mg, 0.24 mmol, 0.08 equiv). The reaction vessel was purged with N_2, and the solution was stirred at 65 °C for 3 h. The crude mixture was passed through a silica plug (EtOAc elution) and concentrated under vacuum. The resulting residue was purified by flash column chromatography (5:1 hex:EtOAc) to afford the sample of **S7** (291 mg, 48%) as a brown crystalline solid.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.54 (d, *J* = 8.8 Hz, 1H, *H4* or *H5*), 7.49 (d, *J* = 8.8 Hz, 1H, *H4* or *H5*), 3.09 (broad s, 1H, O*H*), and 1.67 [s, 6H, C3'(CH_3)$_2$].

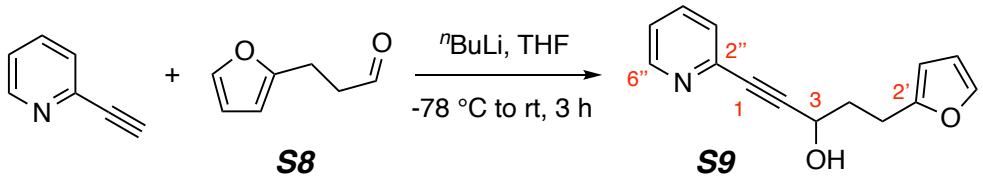
^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 155.3, 146.9, 131.8, 127.9, 100.4, 77.8, 65.5, and 31.1.

IR (neat): 3357 (broad), 3072, 2983, 2934, 2242, 1523, 1399, 1265, 1144, and 1073 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_9H_{10}{}^{35}ClN_2O^+$, 197.0476; found, 197.0469.

mp: 120–123 °C.

(±)-5-(Furan-2-yl)-1-(pyridin-2-yl)pent-1-yn-3-ol (S9)



To a solution of 2-ethynylpyridine (0.27 mL, 2.7 mmol, 1.0 equiv) in THF (10 mL) at -78 °C was added *n*-BuLi (1.30 mL, 3.3 mmol, 1.2 equiv; 2.5 M in THF) dropwise. After the solution stirred for 25 min, a solution of 3-(furan-2-yl)propanal[20] (**S8**, 370 mg, 3.0 mmol, 1.1 equiv) in THF (3 mL) was added dropwise. The mixture was stirred for 1 h at -78 °C and continued to stir for 2 h at room temperature. Water was added and the crude product was extracted with DCM. The organic layer was washed with brine, dried with $MgSO_4$, and concentrated under vacuum. The resulting residue was purified by flash column chromatography (1:1 hex:EtOAc) to afford **S9** (257 mg, 42%) as a brown oil.

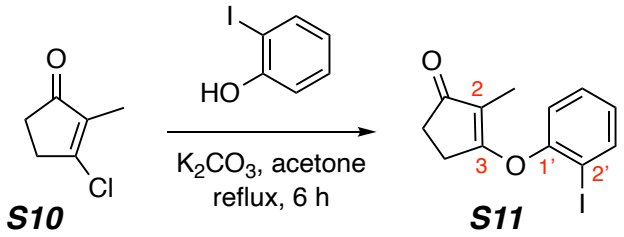
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.56 (ddd, *J* = 4.9, 1.9, 1.0 Hz, 1H, *H6"*), 7.65 (ddd, *J* = 7.7, 7.7, 1.8 Hz, 1H, *H4"*), 7.42 (ddd, *J* = 7.8, 1.1, 1.1 Hz, 1H, *H3"*), 7.30 (dd, *J* = 1.9, 0.9 Hz, 1H, *H5'*), 7.23 (ddd, *J* = 7.6, 4.9, 1.2 Hz, 1H, *H5"*), 6.27 (dd, *J* = 3.2, 1.9 Hz, 1H, *H4'*), 6.04 (ddt, *J* = 3.2, 0.9, 0.9 Hz, 1H, *H3'*), 4.69 (t, *J* = 6.5 Hz, 1H, *H3*), 3.47 (broad s, C3-O*H*), 2.92–2.89 (m, 2H, H5), and 2.21–2.16 (m, 2H, *H4*).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 155.1, 150.0, 142.9, 141.2, 136.4, 127.3, 123.2, 110.3, 105.4, 90.3, 84.3, 61.8, 35.8, and 23.9.

IR (neat): 3450–3000 (broad), 3009, 2953, 2929, 2854, 2230, 1585, 1465, 1428, 1054, and 1004 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{14}H_{14}NO_2^+$, 228.1019; found, 228.1020.

3-(2-Iodophenoxy)-2-methylcyclopent-2-en-1-one (S11)



S10 ***S11***

To a solution of 3-chloro-2-methylcyclopent-2-en-1-one[21] (**S10**, 520 mg, 4.0 mmol, 1.1 equiv) in acetone (3 mL) at room temperature, was added 2-iodophenol (792 mg, 3.6 mmol, 1.0 equiv) and K_2CO_3 (1.03 g, 7.5 mmol, 2.1 equiv). The resulting suspension was refluxed for 6 h. Upon completion, the crude reaction mixture was passed through a silica plug (EtOAc elution) and further purified by flash column chromatography (2:1 hex:EtOAc) to afford **S11** (658 mg, 58%) as a clear light-orange oil.

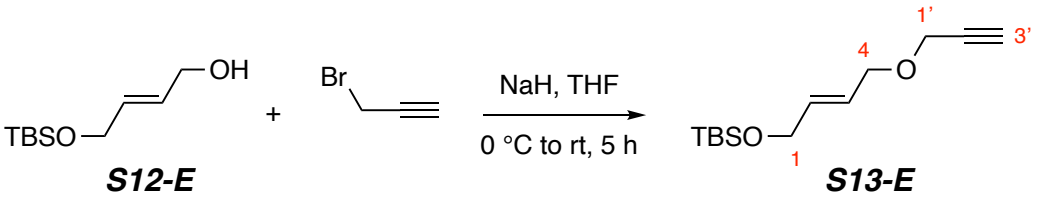
^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.85 (dd, *J* = 7.9, 1.5 Hz, 1H, *H3'*), 7.39 (ddd, *J* = 8.0, 7.4, 1.6 Hz, 1H, *H5'*), 7.15 (dd, *J* = 8.0, 1.5 Hz, 1H, *H6'*), 7.02 (dd, *J* = 7.9, 7.4, 1.5 Hz, 1H, *H4'*), 2.48–2.45 (nfom, 2H, *H4*), 2.41–2.37 (nfom, 2H, *H5*), and 1.66–1.65 (nfom, 3H, C2C*H*$_3$).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 205.7, 180.8, 154.2, 139.9, 129.9, 127.8, 122.1, 119.1, 90.2, 33.9, 26.2, and 6.4.

IR (neat): 3059, 3010, 2920, 2862, 2843, 1696, 1639, 1573, 1462, 1378, 1325, 1225, 1101, and 1020 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{12}H_{12}IO_2^+$, 314.9876; found, 314.9897.

(*E*)-*tert*-Butyldimethyl((4-(prop-2-yn-1-yloxy)but-2-en-1-yl)oxy)silane (S13-*E*)



S12-E ***S13-E***

To a solution of NaH (119 mg, 3.0 mmol, 1.2 equiv; 60% in mineral oil) in THF (7 mL) cooled to 0 °C, was added a solution of (*E*)-4-((*tert*-butyldimethylsilyl)oxy)but-2-en-1-ol[22] (**S12-*E***, 500 mg, 2.5 mmol, 1.0 equiv) in THF (3 mL). The suspension was warmed to room temperature and stirred for 15 min. The reaction mixture was recooled to 0 °C, and propargyl bromide (0.32 mL, 3.0 mmol, 1.2 equiv; 80% in toluene) was added dropwise. The resulting mixture was warmed to room temperature and stirred for 5 h. Water was added and the crude product was extracted with EtOAc. The organic layer was washed with brine, dried with $MgSO_4$, and concentrated under vacuum. The resulting residue was purified by flash column chromatography (9:1 hex:EtOAc) to afford **S13-*E*** (452 mg, 76%) as a yellow oil.

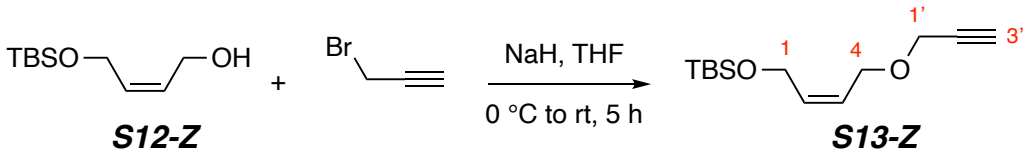
^{1}H-NMR (500 MHz, $CDCl_3$): δ 5.87–5.75 (m, 2H, *H2* & *H3*), 4.20–4.18 (nfom, 2H, *H4* or *H1*), 4.15 (d, J = 2.4 Hz, 2H, *H1'*), 4.09–4.07 (nfom, 2H, *H4* or *H1*), 2.42 (t, J = 2.4 Hz, 1H, *H3'*), 0.91 [s, 9H, Si-C(CH_3)$_3$], and 0.07 [s, 6H, Si(CH_3)$_2$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 133.7, 125.3, 79.9, 74.5, 69.9, 63.1, 57.1, 26.1, 18.5, and -5.1.

IR (neat): 3311, 2954, 2929, 2887, 2855, 1463, 1360, 1253, and 1102 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{13}H_{25}O_2Si^+$, 241.1624; found, 241.1612.

(*Z*)-*tert*-Butyldimethyl((4-(prop-2-yn-1-yloxy)but-2-en-1-yl)oxy)silane (S13-*Z*)



S12-Z ***S13-Z***

To a solution of NaH (119 mg, 3.0 mmol, 1.2 equiv; 60% in mineral oil) in THF (7 mL) cooled to 0 °C, was added a solution of (*Z*)-4-((*tert*-butyldimethylsilyl)oxy)but-2-en-1-ol[22] (**S12-*Z***, 500 mg, 2.5 mmol, 1.0 equiv) in THF (3 mL). The suspension was warmed to room temperature and stirred for 15 min. The reaction mixture was recooled to 0 °C, and propargyl bromide (0.32 mL, 3.0 mmol, 1.2 equiv; 80% in toluene) was added dropwise. The resulting mixture was warmed to room temperature and stirred for 5 h. Water was added and the crude product was extracted with EtOAc. The organic layer was washed with brine, dried with $MgSO_4$, and concentrated under vacuum. The resulting residue was purified by flash column chromatography (9:1 hex:EtOAc) to afford **S13-*Z*** (344 mg, 58%) as a yellow oil.

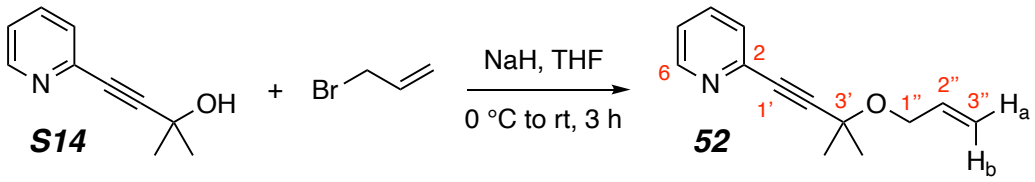
^{1}H-NMR (500 MHz, $CDCl_3$): δ 5.74 (dtt, *J* = 11.2, 6.0, 1.5 Hz, 1H, *H2* or *H3*), 5.57 (dtt, *J* = 11.2, 6.5, 1.7 Hz, 1H, *H2* or *H3*), 4.27 (ddt, *J* = 6.0, 1.7, 0.9 Hz, 2H, *H1* or *H4*), 4.14 (ddt, *J* = 6.4, 1.7, 0.9 Hz, 2H, *H1* or *H4*), 4.14 (d, *J* = 2.4 Hz, 2H, *H1'*), 2.43 (t, *J* = 2.4 Hz, 1H, *H3'*), 0.90 [s, 9H, SiC(CH_3)$_3$], and 0.08 [s, 6H, Si(CH_3)$_2$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 133.9, 126.0, 79.8, 74.6, 65.4, 59.7, 57.3, 26.1, 18.5, and -5.0.

IR (neat): 3310, 2954, 2929, 2886, 2856, 1463, 1316, 1253, and 1074 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{13}H_{25}O_2Si^+$, 241.1624; found, 241.1613.

2-(3-(Allyloxy)-3-methylbut-1-yn-1-yl)pyridine (52)



To a solution of 2-methyl-4-(pyridin-2-yl)but-3-yn-2-ol[23] (**S14**, 465 mg, 2.9 mmol, 1 equiv) in THF (6 mL) cooled to 0 °C, was added NaH (173 mg, 4.3 mmol, 1.5 equiv; 60% in mineral oil). The suspension was warmed to room temperature and stirred for 1 h. The reaction mixture was recooled to 0 °C, and allyl bromide (0.49 mL, 5.7 mmol, 2.0 equiv) was added dropwise. The resulting mixture was warmed to room temperature and stirred for 3 h. Water was added and the crude product was extracted with EtOAc. The organic layer was washed with brine, dried with $MgSO_4$, and concentrated under vacuum. The resulting residue was purified by flash column chromatography (4:1 hex:EtOAc) to afford **52** (200 mg, 34%) as an orange oil.

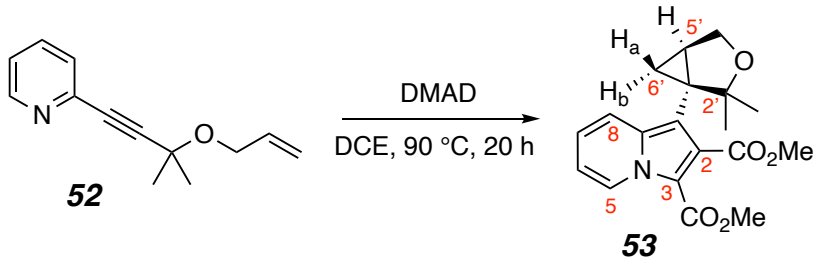
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.58 (ddd, *J* = 4.9, 1.8, 0.9 Hz, 1H, *H6*), 7.65 (ddd, *J* = 7.7, 7.7, 1.8 Hz, 1H, *H4*), 7.42 (ddd, *J* = 7.9, 1.1, 1.1 Hz, 1H, *H3*), 7.23 (ddd, *J* = 7.6, 4.9, 1.2 Hz, 1H, *H5*), 5.98 (ddt, *J* = 17.2, 10.4, 5.6 Hz, 1H, *H2"*), 5.32 (ddt, *J* = 17.2, 1.7, 1.7 Hz, 1H, H_b*3"*), 5.17 (ddt, *J* = 10.4, 1.4, 1.4 Hz, 1H, H_a*3"*), 4.21 (ddd, *J* = 5.6, 1.5, 1.5 Hz, 2H, *H1"*), and 1.61 [s, 6H, C3'(CH_3)$_2$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 150.1, 143.2, 136.2, 135.5, 127.3, 123.0, 116.6, 91.4, 83.8, 70.8, 65.9, and 28.8.

IR (neat): 3079, 3052, 2984, 2934, 2860, 1674, 1581, 1563, 1462, 1427, 1275, 1156, and 1058 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{13}H_{16}NO^+$, 202.1226; found, 202.1240.

(±)-Dimethyl 1-((1*S*,5*R*)-2,2-Dimethyl-3-oxabicyclo[3.1.0]hexan-1-yl)indolizine-2,3-dicarboxylate (53)



A solution of **52** (20 mg, 0.10 mmol, 1 equiv), DMAD (42 mg, 0.30 mmol, 3 equiv), and DCE (1 mL) was charged along with activated 4 Å molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 90 °C for 20 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (3:1 hex:EtOAc) to afford **53** (20 mg, 59%) as a white crystalline solid. The ^{1}H NMR spectrum for this material suggested that the compound exists as a 1.4:1 ratio of slowly interconverting (on the NMR time scale) atropisomers.

Experiment conducted at ambient temperature. A solution of **52** (15 mg, 0.075 mmol, 1 equiv), DMAD (31 mg, 0.22 mmol, 3 equiv), and DCE (0.75 mL) was charged along with activated 4 Å molecular sieves into a threaded culture tube, sealed with a Teflon-lined screw cap, and maintained at room temperature for 47 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (3:1 hex:EtOAc) to afford **53** (21 mg, 82%) as a white crystalline solid.

major atropisomer:
^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.39 (ddd, *J* = 7.2, 1.1, 1.1, Hz, 1H, *H5*), 7.70 (ddd, *J* = 9.0, 1.3, 1.3 Hz, 1H, *H8*), 7.10 (ddd, *J* = 9.0, 6.7, 1.1 Hz, 1H, *H7*), 6.91–6.86 (overlapping m, 1H, *H6)*, 3.97 (dd, *J* = 8.4, 2.7 Hz, 1H, *H4'$_a$*), 3.95 (s, 3H, CO_2CH_3), 3.88 (s, 3H, CO_2CH_3), 3.81 (d, *J* = 8.5 Hz, 1H, *H4'$_b$*), 2.04 (ddd, *J* = 8.0, 4.3, 2.6 Hz, 1H, *H5'*), 1.33 (s, 3H, C2'CH_3), 1.16 (dd, *J* = 4.2, 4.2 Hz, 1H, *H$_a$6'*), 1.06 (s, 3H, C2'CH_3), and 0.70 (dd, *J* = 7.9, 4.0 Hz, 1H, *H$_b$6'*).
^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 167.7, 160.8, 137.1, 128.7, 127.6, 122.67, 118.7, 114.3, 111.2, 110.3, 82.8, 66.9, 52.53, 51.7, 30.7, 25.0, 24.1, 23.8, and 13.5.

minor atropisomer:
^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.41 (ddd, *J* = 7.2, 1.1, 1.1, Hz, 1H, *H5*), 7.64 (ddd, *J* = 9.0, 1.3, 1.3 Hz, 1H, *H8*), 7.12 (ddd, *J* = 9.0, 6.6, 2.1 Hz, 1H, *H7*), 6.91–6.86 (overlapping m, 1H, *H6)*, 4.16 (dd, *J* = 8.6, 2.7 Hz, 1H, *H4'$_a$*), 3.90 (d, *J* = 8.6, 1H, *H4'$_b$*), 3.95 (s, 3H, CO_2CH_3), 3.88 (s, 3H, CO_2CH_3), 1.84 (ddd, *J* = 8.0, 4.2, 2.6 Hz, 1H, *H5'*), 1.29 (s, 3H, C2'CH_3), 1.06 (s, 3H, C2'CH_3), 1.06 (dd, *J* = 4.5, 4.5 Hz, 1H, *H$_a$6'*), and 0.93 (dd, *J* = 7.9, 4.6 Hz, 1H, *H$_b$6'*).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 167.4, 160.7, 136.5, 130.2, 127.7, 122.71, 118.6, 114.0, 111.0, 110.4, 83.3, 66.8, 52.48, 51.7, 30.6, 24.0, 23.9, 23.7, and 13.8.

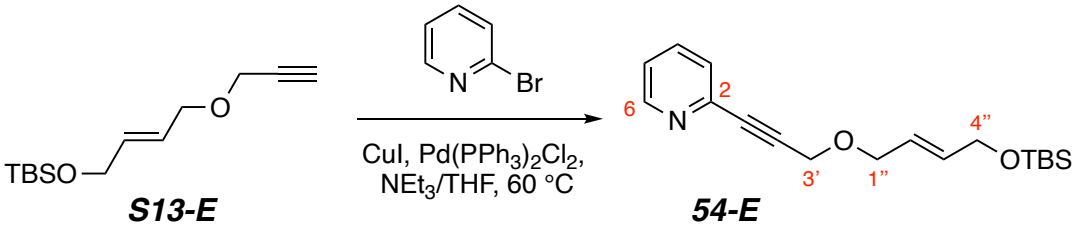
The following data are taken from the mixture of atropisomers:

IR (neat): 3122, 3075, 2974, 2951, 2851, 1737, 1691, 1389, 1213, and 1179 cm^{-1}.

HRMS (ESI-TOF) *m/z* [$M+H^+$]: calcd for $C_{19}H_{22}NO_5^+$, 344.1492; found, 344.1520.

mp: 144–147 °C.

(*E*)-2-(3-((4-((*tert*-Butyldimethylsilyl)oxy)but-2-en-1-yl)oxy)prop-1-yn-1-yl)pyridine (54-*E*)



To a solution of 2-bromopyridine (116 µL, 1.2 mmol, 1.0 equiv) and **S13-*E*** (351 mg, 1.5 mmol, 1.2 equiv) in Et_3N (3 mL) and THF (3 mL) was added $Pd(PPh_3)_2Cl_2$ (18 mg, 0.026 mmol, 0.02 equiv) and CuI (10 mg, 0.053 mmol, 0.04 equiv). The reaction vessel was purged with N_2, and then the solution was stirred at 60 °C for 3.5 h. Upon completion, the crude mixture was passed through a silica plug (EtOAc elution) and concentrated under vacuum. The residue was purified by flash column chromatography (3:1 → 2:1 hex:EtOAc) to afford **54-*E*** (160 mg, 35%) as a yellow oil.

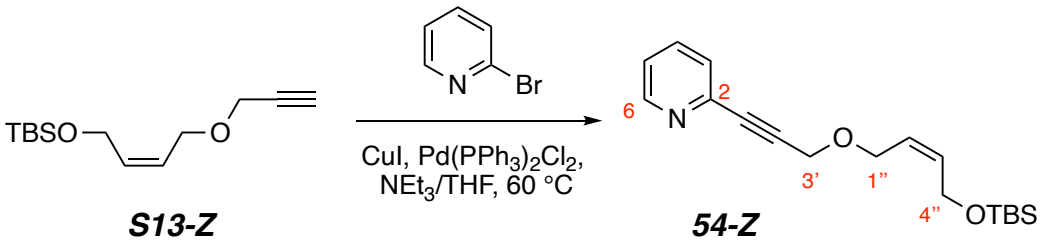
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.58 (ddd, *J* = 4.9, 1.9, 1.0 Hz, 1H, *H6*), 7.65 (ddd, *J* = 7.8, 7.8, 1.8 Hz, 1H, *H4*), 7.44 (ddd, *J* = 7.8, 1.1, 1.1 Hz, 1H, *H3*), 7.24 (ddd, *J* = 7.7, 4.9, 1.2 Hz, 1H, *H5*), 5.90–5.78 (m, 2H, *H2"* & *H3"*), 4.41 (s, 2H, *H3'*), 4.20 (ddt, *J* = 3.9, 1.2, 1.2 Hz, 1H, *H1"* or *H4"*), 4.16 (ddt, *J* = 5.7, 1.3, 1.3 Hz, 1H, *H1"* or *H4"*), 0.91 [s, 9H, Si-C(CH_3)$_3$], and 0.07 [s, 6H, Si(CH_3)$_2$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 150.1, 143.0, 136.3, 133.7, 127.3, 125.3, 123.1, 85.6, 85.4, 70.1, 63.1, 57.7, 26.1, 18.5, and -5.1.

IR (neat): 2953, 2929, 2884, 2854, 1582, 1462, 1353, 1253, 1102, and 1047 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{18}H_{28}NO_2Si^+$, 318.1884; found, 318.1875.

(*Z*)-2-(3-((4-((*tert*-Butyldimethylsilyl)oxy)but-2-en-1-yl)oxy)prop-1-yn-1-yl)pyridine (54-*Z*)



S13-Z ***54-Z***

To a solution of 2-bromopyridine (76 µL, 0.80 mmol, 1.0 equiv) and **S13-*Z*** (230 mg, 0.96 mmol, 1.2 equiv) in Et_3N (2 mL) and THF (2 mL) was added $Pd(PPh_3)_2Cl_2$ (12 mg, 0.017 mmol, 0.02 equiv) and CuI (7 mg, 0.037 mmol, 0.05 equiv). The reaction vessel was purged with N_2, and then the solution was stirred at 60 °C for 3.5 h. Upon completion, the crude mixture was passed through a silica plug (EtOAc elution) and concentrated under vacuum. The residue was purified by flash column chromatography (3:1 → 2:1 hex:EtOAc) to afford **54-*Z*** (148 mg, 49%) as a yellow oil.

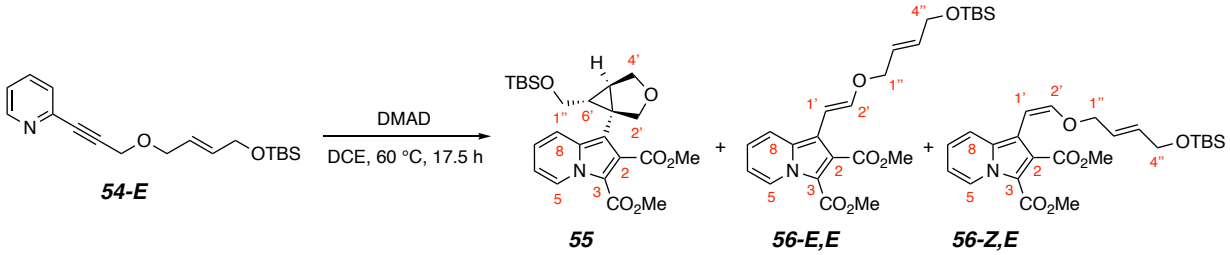
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.58 (ddd, *J* = 4.9, 1.9, 1.0 Hz, 1H, *H6*), 7.65 (ddd, *J* = 7.7, 7.7, 1.8 Hz, 1H, *H4*), 7.44 (ddd, *J* = 7.8, 1.1, 1.1 Hz, 1H, *H3*), 7.24 (ddd, *J* = 7.7, 4.9, 1.2 Hz, 1H, *H5*), 5.75 (dtt, *J* = 11.2, 6.0, 1.5 Hz, 2H, *H2"* or *H3"*), 5.61 (dtt, *J* = 11.2, 6.4, 1.7 Hz, 1H, *H2"* or *H3"*), 4.40 (s, 2H, *H3'*), 4.29 (ddt, *J* = 6.0, 1.7, 0.9 Hz, 1H, *H1"* or *H4"*), 4.22 (ddt, *J* = 6.5, 1.7, 0.9 Hz, 1H, *H1"* or *H4"*), 0.89 [s, 9H, Si-C(CH_3)$_3$], and 0.06 [s, 6H, Si(CH_3)$_2$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 150.2, 142.9, 136.2, 133.9, 127.2, 126.0, 123.2, 85.8, 85.3, 65.7, 59.7, 57.9, 26.0, 18.4, and -5.1.

IR (neat): 2953, 2929, 2885, 2855, 1582, 1462, 1428, 1359, 1253, and 1072 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{18}H_{28}NO_2Si^+$, 318.1884; found, 318.1875.

(±)-Dimethyl 1-((1*R*,5*R*,6*R*)-6-(((*tert*-Butyldimethylsilyl)oxy)methyl)-3-oxabicyclo[3.1.0]hexan-1-yl)indolizine-2,3-dicarboxylate (55)
and
Dimethyl 1-((*E*)-2-(((*E*)-4-((*tert*-Butyldimethylsilyl)oxy)but-2-en-1-yl)oxy)vinyl)indolizine-2,3-dicarboxylate (56-*E,E*)
and
Dimethyl 1-((*Z*)-2-(((*E*)-4-((*tert*-Butyldimethylsilyl)oxy)but-2-en-1-yl)oxy)vinyl)indolizine-2,3-dicarboxylate (56-*Z,E*)



A solution of **54-*E*** (30 mg, 0.094 mmol, 1 equiv), DMAD (40 mg, 0.28 mmol, 3 equiv), and DCE (2 mL) was charged with 4 Å molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 60 °C for 17.5 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (7:1 hex:EtOAc) to afford, in order of elution, **56-*Z,E*** (3 mg, 5%), **56-*E,E*** (10 mg, 35%), and **55** (17 mg, 48%), each as a clear yellow oil.

The two enol-ether isomers **56-*E,E*** and **56-*Z,E*** were initially separated using MPLC. However, when samples enriched in one or the other of the two isomers are independently dissolved in $CDCl_3$, isomerization of the geometric isomers is observed, likely due to trace acid (HCl) present in the solvent. Each mixture eventually equilibrated to an ~1:1.3 ratio of the cis- to trans-isomers.

Data for 55 (cyclopropane):

The ^{1}H NMR spectrum for this material suggests that it exists as a 3.9:1 ratio of slowly interconverting (on the NMR time scale) atropisomers.

major atropisomer:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.36 (ddd, *J* = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 7.71 (ddd, *J* = 8.9, 1.3, 1.3 Hz, 1H, *H8*), 7.06 (ddd, *J* = 8.9, 6.7, 1.1 Hz, 1H, *H7*), 6.88 (ddd, *J* = 7.1, 6.7, 1.4 Hz, 1H, *H6*), 4.10 (d, *J* = 8.1 Hz, 1H, C2'H_aH_b), 3.99 (d, *J* = 8.2 Hz, 1H, C4'H_aH_b), 3.94 (s, 3H, CO_2CH_3), 3.88 (s, 3H, CO_2CH_3'), 3.86 (dd, *J* = 8.2, 2.8 Hz, 1H, C4'H_aH_b), 3.67 (d, *J* = 8.1 Hz, 1H, C2'H_aH_b), 3.51 (dd, *J* = 11.0, 5.6 Hz, 1H, C1''H_aH_b), 3.27 (dd, *J* = 11.0, 7.8 Hz, 1H, C1''H_aH_b), 1.69 (dd, *J* = 4.1, 2.7 Hz, 1H, *H5'*), 1.55 (ddd, *J* = 7.7, 5.6, 4.0 Hz, 1H, *H6'*), 0.77 [s, 9H, Si-C(CH_3)$_3$], -0.15 (s, 3H, SiCH_3), and -0.21 (s, 3H, SiCH_3').

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 167.5, 160.7, 137.4, 128.8, 127.3, 122.4, 119.3, 114.4, 110.0, 108.2, 74.3, 70.0, 62.2, 52.7, 51.7, 29.0, 26.5, 26.2, 26.0, 18.3, -5.36, and -5.43.

minor atropisomer:
^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.39 (ddd, *J* = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 7.56 (ddd, *J* = 9.0, 1.3, 1.3 Hz, 1H, *H8*), 7.10 (ddd, *J* = 9.0, 6.7, 1.1 Hz, 1H, *H7*), 6.90–6.87 (overlapping multiplet, 1H, *H6*), 4.14–4.11 (m, 2H, C4'H_aH$_b$ and C4'H$_a$$H_b$), 4.09 (d, *J* = 8.4 Hz, 1H, C2'H_aH$_b$), 3.97 (d, *J* = 11.2, 4.2 Hz, 1H, C1''H_aH$_b$), 3.95 (s, 3H, CO_2CH_3), 3.88 (s, 3H, CO_2CH_3'), 3.56 (d, *J* = 8.4 Hz, 1H, C2'H$_a$$H_b$), 2.96 (dd, *J* = 11.3, 8.7 Hz, 1H, C1''H$_a$$H_b$), 2.10 (dd, *J* = 3.9, 2.2 Hz, 1H, *H5'*), 1.45 (ddd, *J* = 8.5, 4.1, 4.1 Hz, 1H, *H6'*), 0.76 [s, 9H, Si-C(CH_3)$_3$], -0.06 (s, 3H, SiCH_3), and -0.13 (s, 3H, SiCH_3').

Partial carbon data:
^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 166.9, 160.9, 135.3, 129.3, 127.7, 122.7, 117.9, 114.3, 109.2, 75.0, 70.3, 62.1, 52.5, 51.7, 28.2, 28.0, 26.3, 25.9, -5.2, and -5.3. (two resonances not observed for the minor atropisomer)

The following data are taken from the mixture of atropisomers:

IR (neat): 2952, 2928, 2854, 1736, 1691, 1503, 1439, 1390, 1209, and 1054 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{24}H_{34}NO_6Si^+$, 460.2150; found, 460.2136.

Data for 56-*E,E* extracted from the spectra of an ca. 4.5:1 ratio of a mixture 56-*Z,E*:56-*E,E*:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.35 (ddd, *J* = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 7.57 (ddd, *J* = 9.0, 1.2, 1.2 Hz, 1H, *H8*), 7.05 (ddd, *J* = 9.0, 6.7, 1.2 Hz, 1H, *H7*), 6.85 (ddd, *J* = 7.2, 6.6, 1.4 Hz, 1H, *H6*), 6.83 (d, *J* = 13.0 Hz, 1H, *H2'*), 5.93 (d, *J* = 13.0 Hz, 1H, *H1'*), 5.91–5.82 (m, 2H, *H2''* & *H3''*), 4.41–4.37 (m, 2H, *H1''* or *H4''*), 4.24–4.21 (m, 2H, *H1''* or *H4''*), 3.94 (s, 3H, CO_2CH_3), 3.88 (s, 3H, CO_2CH_3'), 0.92 [s, 9H, Si-C(CH_3)$_3$], and 0.08 [s, 6H, Si(CH_3)$_2$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 167.6, 160.9, 148.8, 134.2, 133.8, 127.4, 126.4, 124.5, 122.5, 118.2, 114.4, 111.4, 109.7, 96.0, 70.3, 63.03, 52.7, 51.7, 26.08, 18.52, and -5.12.

Data for 56-*Z,E* extracted from the spectra of an ca. 4.5:1 ratio of a mixture 56-*Z,E*:56-*E,E*:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.39 (ddd, *J* = 7.2, 1.2, 1.2 Hz, 1H, *H5*), 7.71 (ddd, *J* = 9.0, 1.3, 1.3 Hz, 1H, *H8*), 7.04 (ddd, *J* = 9.1, 6.7, 1.2 Hz, 1H, *H7*), 6.85 (ddd, *J* = 7.2, 6.7, 1.4 Hz, 1H, *H6*), 6.22 (d, *J* = 7.0 Hz, 1H, *H2'*), 5.90–5.79 (m, 2H, *H2''* & *H3''*), 5.39 (d, *J* = 7.0 Hz, 1H, *H1'*), 4.41–4.37 (m, 2H, *H1''* or *H4''*), 4.20–4.17 (m, 2H, *H1''* or *H4''*), 3.92 (s, 3H, CO_2CH_3), 3.88 (s, 3H, CO_2CH_3'), 0.90 [s, 9H, Si-C(CH_3)$_3$], and 0.06 [s, 6H, Si(CH_3)$_2$].

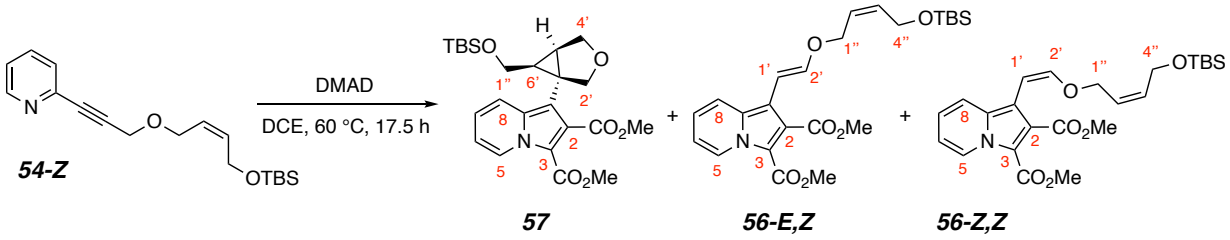
^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 167.5, 161.1, 145.1, 134.5, 133.6, 127.2, 126.3, 124.9, 122.0, 120.0, 114.3, 111.0, 109.2, 95.3, 72.9, 62.99, 52.5, 51.6, 26.06, 18.52, and -5.14.

The following data are taken from the mixture of 56-*E,E* and 56-*Z,E*:

IR (neat): 2952, 2929, 2856, 1736, 1690, 1497, 1440, 1386, 1213, 1125, and 1103 cm^{-1}.

HRMS (ESI-TOF) *m/z* [$M+H^+$]: calcd for $C_{24}H_{34}NO_6Si^+$, 460.2150; found, 460.2137.

(±)-Dimethyl 1-((1*R*,5*R*,6*S*)-6-(((*tert*-Butyldimethylsilyl)oxy)methyl)-3-oxabicyclo[3.1.0]hexan-1-yl)indolizine-2,3-dicarboxylate (57)
and
Dimethyl 1-((*E*)-2-(((*Z*)-4-((*tert*-butyldimethylsilyl)oxy)but-2-en-1-yl)oxy)vinyl)indolizine-2,3-dicarboxylate (56-*E,Z*)
and
Dimethyl 1-((*Z*)-2-(((*Z*)-4-((*tert*-Butyldimethylsilyl)oxy)but-2-en-1-yl)oxy)vinyl)indolizine-2,3-dicarboxylate (56-*Z,Z*)



A solution of **54-*Z*** (30 mg, 0.094 mmol, 1 equiv), DMAD (40 mg, 0.28 mmol, 3 equiv), and DCE (2 mL) was charged with 4 Å molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 60 °C for 17.5 h. The crude mixture was passed through a silica plug (EtOAc elution) and the eluant concentrated under vacuum. The residue was purified using MPLC (7:1 hex:EtOAc) to afford, in order of elution, **56-*Z,Z*** (3 mg, 7%) and **56-*E,Z*** (10 mg, 23%), each as a clear yellow oil, and **57** (17 mg, 39%) as a white crystalline solid.

The two enol-ether isomers **56-*E,Z*** and **56-*Z,Z*** were initially separated using MPLC. However, when samples of enriched in one or the other of the two isomers are independently dissolved in $CDCl_3$, isomerization of the geometric isomers is observed, likely due to trace acid (HCl) present in the solvent. Each mixture eventually equilibrated to an ~1:1.6 ratio of the cis- to trans-isomers.

Data for 57 (cyclopropane):

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.34 (ddd, *J* = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 8.22 (ddd, *J* = 9.0, 1.3, 1.3 Hz, 1H, *H8*), 7.04 (ddd, *J* = 9.0, 6.7, 1.1 Hz, 1H, *H7*), 6.87 (ddd, *J* = 7.1, 6.7, 1.4 Hz, 1H, *H6*), 4.16 (d, *J* = 8.6 Hz, 1H, C2'H_aH$_b$), 4.12 (dd, *J* = 8.8, 3.6 Hz, 1H, C4'H_aH$_b$), 4.04–3.95 (m, 4H, C2'H$_a$$H_b$, C4'H$_a$$H_b$, C1''$H_aH_b$, C1''H$_a$$H_b$), 3.96 (s, 3H, CO_2CH_3), 3.88 (s, 3H, CO_2CH_3'), 1.95 (dd, *J* = 8.5, 3.4 Hz, 1H, *H5'*), 1.58 (dddd, *J* = 9.2, 8.5, 5.5, 1.0 Hz, 1H, *H6'*), 0.97 [s, 9H, Si-C(CH_3)$_3$], 0.140 (s, 3H, SiCH_3), and 0.136 (s, 3H, SiCH_3').

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 167.4, 160.9, 137.0, 127.7, 127.3, 122.6, 118.8, 114.5, 111.9, 110.0, 72.9, 68.9, 58.0, 52.7, 51.7, 28.49, 28.47, 28.0, 26.1, 18.5, -5.1, and -5.2.

IR (neat): 2953, 2929, 2857, 1737, 1664, 1505, 1439, 1387, 1217, and 1063 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{24}H_{34}NO_6Si^+$, 460.2150; found, 460.2138.

mp: 102–105 °C.

Partial data for 56-*E,Z* extracted from the ^{1}H spectrum of the mixture:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.36 (ddd, *J* = 7.2, 1.0, 1.0 Hz, 1H, *H5*), 7.57 (ddd, *J* = 9.0, 1.2, 1.2 Hz, 1H, *H8*), 7.08–7.03 (overlapping m, 1H, *H7*), 6.88–6.84 (overlapping m, 1H, *H6*), 6.83 (d, *J* = 13.0 Hz, 1H, *H2'*), 5.90 (d, *J* = 13.0 Hz, 1H, *H1'*), 5.79–5.58 (overlapping m, 2H, *H2"* and *H3"*), 4.50–4.47 (overlapping m, 2H, *H1"* or *H4"*), 4.30 (ddt, *J* = 5.7, 1.9, 1.0 Hz, 2H, *H1"* or *H4"*), 3.95 (s, 3H, CO_2CH_3), 3.88 (s, 3H, CO_2CH_3'), 0.91 [s, 9H, Si-C(CH_3)$_3$], and 0.09 [s, 6H, Si(CH_3)$_2$].

Partial data for 56-*Z,Z* extracted from the ^{1}H spectrum of the mixture:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.37 (ddd, *J* = 7.1, 1.1, 1.1 Hz, 1H, *H5*), 7.69 (ddd, *J* = 9.0, 1.2, 1.2 Hz, 1H, *H8*), 7.08–7.03 (overlapping m, 1H, *H7*), 6.88–6.84 (overlapping m, 1H, *H6*), 6.21 (d, *J* = 6.9 Hz, 1H, *H2'*), 5.79–5.58 (overlapping m, 2H, *H2"* and *H3"*), 5.40 (d, *J* = 6.9 Hz, 1H, *H1'*), 4.50–4.47 (overlapping m, 2H, *H1"* or H4"), 4.23 (ddt, *J* = 5.7, 1.8, 1.0 Hz, 2H, *H1"* or *H4"*), 3.92 (s, 3H, CO_2CH_3), 3.88 (s, 3H, CO_2CH_3'), 0.89 [s, 9H, Si-C(CH_3)$_3$], and 0.06 [s, 6H, Si(CH_3)$_2$].

Partial carbon data for the mixture of 56-*E,Z* and 56-*Z,Z*:

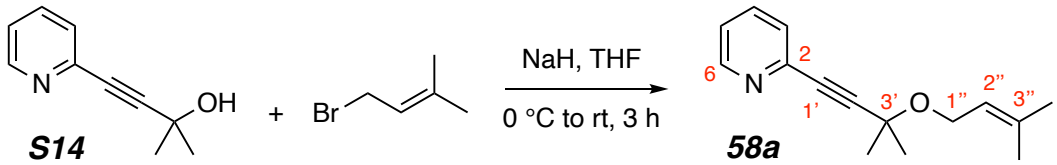
^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 167.6, 160.9, 148.7, 145.0, 134.2, 133.4, 133.3, 127.4, 127.2, 125.9, 125.5, 125.2, 122.5, 122.1, 119.9, 118.2, 114.4, 114.3, 109.6, 95.9, 95.6, 66.0, 59.9, 59.8, 52.8, 52.5, 51.7, 26.1, 26.0, -5.05, and -5.11.

The following data are taken from the mixture of 56-*E,Z* and 56-*Z,Z* isomers:

IR (neat): 2952, 2928, 2856, 1736, 1691, 1498, 1440, 1386, 1213, and 1100 cm^{-1}.

HRMS (ESI-TOF) *m/z* [$M+H^+$]: calcd for $C_{24}H_{34}NO_6Si^+$, 460.2150; found, 460.2136.

2-(3-Methyl-3-((3-methylbut-2-en-1-yl)oxy)but-1-yn-1-yl)pyridine (58a)



To a solution of 2-methyl-4-(pyridin-2-yl)but-3-yn-2-ol[23] (**S14**, 465 mg, 2.9 mmol, 1 equiv) in THF (6 mL) cooled to 0 °C, was added NaH (173 mg, 4.3 mmol, 1.5 equiv; 60% in mineral oil). The suspension was warmed to room temperature and stirred for 1 h. The reaction mixture was recooled to 0 °C, and allyl bromide 1-bromo-3-methylbut-2-ene (0.66 mL, 5.6 mmol, 1.9 equiv) was added dropwise. The resulting mixture was warmed to room temperature and stirred for 3 h. Water was added and the crude product was extracted with EtOAc. The organic layer was washed with brine, dried with $MgSO_4$, and concentrated under vacuum. The resulting residue was purified by flash column chromatography (4:1 hex:EtOAc) to afford **58a** (102 mg, 15%) as an orange oil.

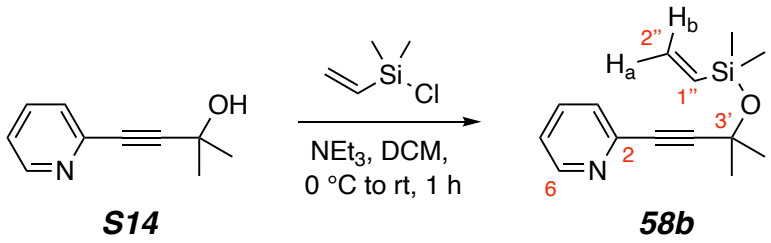
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.58 (ddd, *J* = 4.9, 1.7, 0.9 Hz, 1H, *H6*), 7.65 (ddd, *J* = 7.8, 7.8, 1.8 Hz, 1H, *H4*), 7.42 (ddd, *J* = 7.8, 1.0, 1.0 Hz, 1H, *H3*), 7.23 (ddd, *J* = 7.6, 4.9, 1.2 Hz, 1H, *H5*), 5.40 (tqq, *J* = 7.0, 1.4, 1.4 Hz, 1H, *H2"*), 4.19 (br d, *J* = 7.0 Hz, 2H, *H1"*), 1.75 (dt, *J* = 1.3, 1.3 Hz, 3H, =CC*H*$_3$), 1.71 (dt, *J* = 2.0, 0.6 Hz, 3H, =CC*H*$_3$), and 1.61 [s, 6H, C3'(C*H*$_3$)$_2$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 150.1, 143.3, 137.0, 136.2, 127.3, 122.9, 121.5, 91.8, 83.7, 70.4, 61.3, 28.9, 26.0, and 18.2.

IR (neat): 3077, 3051, 2982, 2931, 2914, 2860, 1582, 1562, 1462, 1427, 1274, 1155, and 1035 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{15}H_{20}NO^+$, 230.1539; found, 230.1554.

2-(3-((Dimethyl(vinyl)silyl)oxy)-3-methylbut-1-yn-1-yl)pyridine (58b)



S14 ***58b***

To a solution of 2-methyl-4-(pyridin-2-yl)but-3-yn-2-ol[23] (**S14**, 150 mg, 0.93 mmol, 1.0 equiv) in DCM (5 mL) was added NEt_3 (0.26 mL, 1.86 mmol, 2.0 equiv) and chloro(dimethyl)vinylsilane (0.19 mL, 1.38 mmol, 1.5 equiv) under N_2 at 0 °C. The solution was warmed to room temperature and stirred for 1 h. Water was added and the crude product was extracted with DCM. The organic layer was washed with brine, dried with $MgSO_4$, and concentrated under vacuum. The resulting residue was purified by flash column chromatography (6:1 hex:EtOAc) to afford **58b** (204 mg, 89%) as a clear colorless oil.

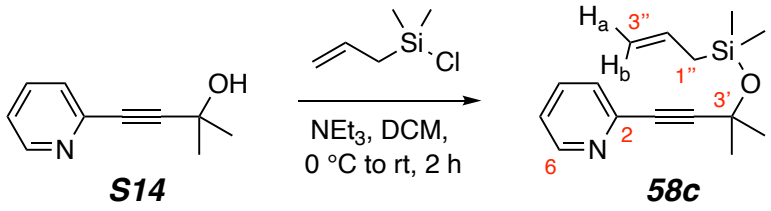
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.58 (ddd, *J* = 5.0, 1.9, 1.0 Hz, 1H, *H6*), 7.64 (ddd, *J* = 7.7, 7.7, 1.9 Hz, 1H, *H4*), 7.39 (ddd, *J* = 7.9, 1.1, 1.1 Hz, 1H, *H3*), 7.22 (ddd, *J* = 7.7, 4.9, 1.3 Hz, 1H, *H5*), 6.30 (dd, *J* = 20.4, 14.9 Hz, 1H, *H1"*), 5.97 (dd, *J* = 14.8, 3.7 Hz, 1H, H_a*2"*), 5.78 (dd, *J* = 20.5, 3.7 Hz, 1H, H_b*2"*), 1.61 [s, 6H, C3'(CH_3)$_2$], and 0.32 [s, 6H, Si(CH_3)$_2$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 150.2, 143.4, 139.5, 136.2, 132.1, 127.0, 122.9, 94.3, 82.7, 67.3, 32.9, and 0.2.

IR (neat): 3078, 3050, 2984, 2967, 2902, 1582, 1462, 1427, 1275, 1250, 1155, and 1079 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{14}H_{20}NOSi^+$, 246.1309; found, 246.1324.

2-(3-((Allyldimethylsilyl)oxy)-3-methylbut-1-yn-1-yl)pyridine (58c)



S14 ***58c***

To a solution of 2-methyl-4-(pyridin-2-yl)but-3-yn-2-ol[23] (**S14**, 150 mg, 0.93 mmol, 1.0 equiv) in DCM (5 mL) was added NEt_3 (0.26 mL, 1.86 mmol, 2.0 equiv) and allyl(chloro)dimethylsilane (0.21 mL, 1.39 mmol, 1.4 equiv) under N_2 at 0 °C. The solution was warmed to room temperature and stirred for 2 h. Water was added and the crude product was extracted with DCM. The organic layer was washed with brine, dried with $MgSO_4$, and concentrated under vacuum. The resulting residue was purified by flash column chromatography (6:1 hex:EtOAc) to afford **58c** (204 mg, 89%) as a clear colorless oil.

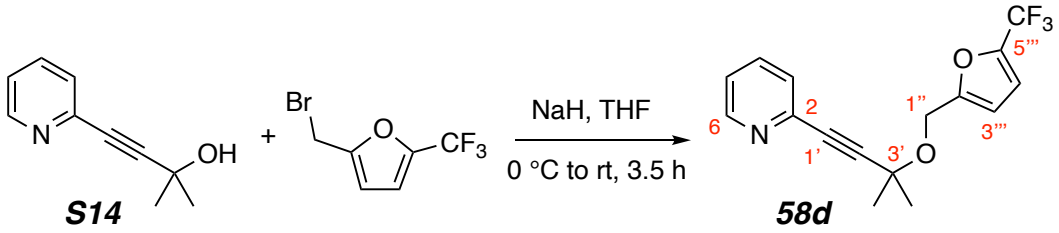
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.59 (ddd, *J* = 4.9, 1.9, 1.0 Hz, 1H, *H6*), 7.65 (ddd, *J* = 7.8, 7.8, 1.9 Hz, 1H, *H4*), 7.40 (ddd, *J* = 7.9, 1.1, 1.1 Hz, 1H, *H3*), 7.22 (ddd, *J* = 7.7, 4.9, 1.2 Hz, 1H, *H5*), 5.84 (ddt, *J* = 17.0, 10.1, 8.1 Hz, 1H, *H2"*), 4.89 (ddt, *J* = 17.0, 2.4, 1.4 Hz, 1H, *H_b3"*), 4.85 (ddt, *J* = 10.0, 2.2, 1.1 Hz, 1H, *H_a3"*), 1.75 (ddd, *J* = 8.1, 1.4, 1.0 Hz, 2H, *H1"*), 1.61 [s, 6H, C3'(CH_3)$_2$], and 0.26 [s, 6H, Si(CH_3)$_2$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 150.2, 143.3, 136.3, 134.7, 126.9, 122.9, 113.6, 94.3, 82.7, 67.1, 32.9, 26.2, and 0.1.

IR (neat): 3077, 3058, 2984, 2933, 1630, 1582, 1462, 1427, 1275, 1252, 1149, and 1029 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{15}H_{22}NOSi^+$, 260.1465; found, 260.1480.

2-(3-Methyl-3-((5-(trifluoromethyl)furan-2-yl)methoxy)but-1-yn-1-yl)pyridine (58d)



To a solution of 2-methyl-4-(pyridin-2-yl)but-3-yn-2-ol[23] (**S14**, 188 mg, 1.2 mmol, 1 equiv) in THF (3 mL), cooled to 0 °C, was added NaH (70 mg, 1.8 mmol, 1 equiv; 60% in mineral oil). The suspension was warmed to room temperature and stirred for 15 min. The reaction mixture was recooled to 0 °C, and a solution of 2-(bromomethyl)-5-(trifluoromethyl)furan (237 µL, 1.8 mmol, 1.5 equiv) in THF (2 mL) was added dropwise. The resulting mixture was warmed to room temperature and stirred for 3.5 h. Water was added and the crude product was extracted with EtOAc. The organic layer was washed with brine, dried with $MgSO_4$, and concentrated under vacuum. The resulting residue was purified by flash column chromatography (3:1→ 2:1 hex:EtOAc) to afford **58d** (134 mg, 37%) as a yellow oil.

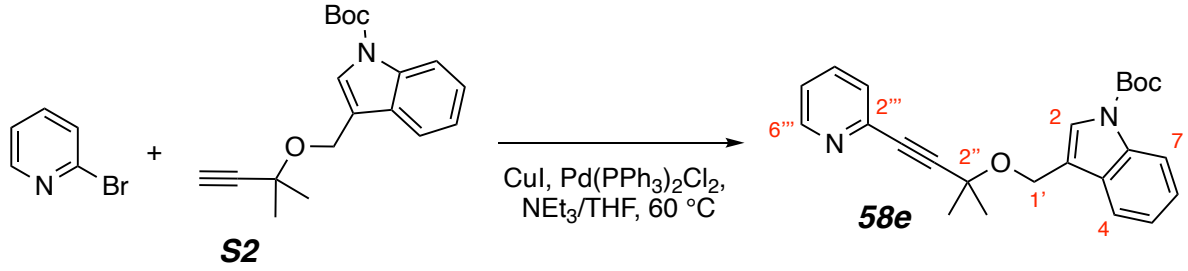
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.59 (ddd, *J* = 4.9, 1.9, 1.0 Hz, 1H, *H6*), 7.66 (ddd, *J* = 7.8, 7.8, 1.8 Hz, 1H, *H4*), 7.44 (ddd, *J* = 7.8, 1.1, 1.1 Hz, 1H, *H3*), 7.25 (ddd, *J* = 7.7, 4.9, 1.2 Hz, 1H, *H5*), 6.73 (dq, *J* = 3.6, 1.3 Hz, 1H, *H4'''*), 6.41 (dq, *J* = 3.4, 0.8 Hz, 1H, *H3'''*), 4.71 (q, *J* = 0.6 Hz, 2H, H1"), and 1.64 [s, 6H, C3'(CH_3)$_2$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 155.5 (C2''', q, *J* = 1.4 Hz), 150.2 (C6), 142.9 (C2), 141.6 (C5''', q, *J* = 42.7 Hz), 136.3 (C4), 127.4 (C3), 123.2 (C5), 119.2 (q, *J* = 263 Hz), 112.5 (C4''', q, *J* = 2.7 Hz), 109.4 (C3'''), 90.5, 84.6, 71.6, 59.2, and 28.8.

IR (neat): 3055, 2988, 2937, 2868, 1583, 1564, 1463, 1318, 1126, 1104, and 1051 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{16}H_{15}F_3NO_2^+$, 310.1049; found, 310.1041.

***tert*-Butyl 3-(((2-Methyl-4-(pyridin-2-yl)but-3-yn-2-yl)oxy)methyl)-1*H*-indole-1-carboxylate (58e)**



To a solution of 2-bromopyridine (58 µL, 0.61 mmol, 1.0 equiv) and **S2** (209 mg, 0.67 mmol, 1.1 equiv) in Et_3N (1 mL) and THF (1 mL) was added $Pd(PPh_3)_2Cl_2$ (9 mg, 0.013 mmol, 0.02 equiv) and CuI (5 mg, 0.026 mmol, 0.04 equiv). The reaction vessel was purged with N_2, and the solution was stirred at 60 °C for 4 h. The crude mixture was passed through a silica plug (EtOAc elution) and concentrated under vacuum. The residue was purified by flash column chromatography (3:1 → 1:1 hex:EtOAc) to afford **58e** (179 mg, 69%) as a yellow oil.

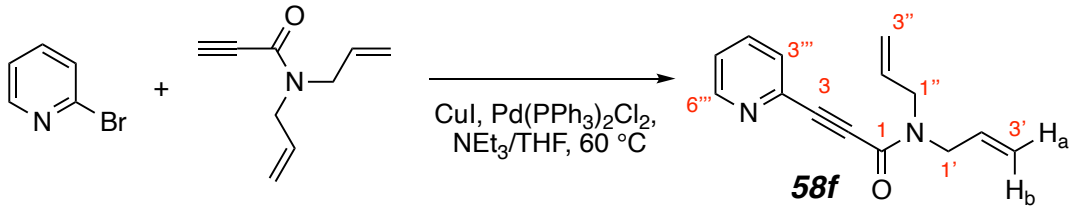
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.61 (ddd, *J* = 4.9, 1.9, 1.0 Hz, 1H, *H6'''*), 8.13 (broad m, *J* = 7.6 Hz, 1H, *H7*), 7.72 (ddd, *J* = 7.8, 1.3, 0.8 Hz, 1H, *H4*), 7.66 (ddd, *J* = 7.8, 7.8, 1.9 Hz, 1H, *H4'''*), 7.61 (broad s, 1H, *H2*), 7.46 (ddd, *J* = 7.8, 1.1, 1.1 Hz, 1H, *H3'''*), 7.31 (ddd, *J* = 8.4, 7.2, 1.3 Hz, 1H, *H6*), 7.26–7.21 (m, 2H, *H5''' & H5*), 4.88 (d, *J* = 1.0 Hz, 2H, *H1'*), 1.70 [s, 6H, C2''(CH_3)$_2$], and 1.65 [s, 9H, C(CH_3)$_3$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 150.2, 149.8, 143.1, 136.3, 135.9, 129.9, 127.4, 124.58, 124.56, 123.1, 122.7, 119.8, 118.2, 115.3, 91.4, 84.2, 83.6, 71.1, 58.9, 28.9, and 28.3.

IR (neat): 3052, 2982, 2934, 2867, 1731, 1582, 1452, 1352, 1257, 1153, and 1088 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{24}H_{27}N_2O_3^+$, 391.2016; found, 391.2008.

_N_,_N_-Diallyl-3-(pyridin-2-yl)propiolamide (58f)



To a solution of 2-bromopyridine (0.14 mL, 1.5 mmol, 1.0 equiv) and *N*,*N*-diallylpropiolamide[24] (242 mg, 1.6 mmol, 1.1 equiv) in Et_3N (2 mL) and THF (2 mL) was added $Pd(PPh_3)_2Cl_2$ (20 mg, 0.03 mmol, 0.02 equiv) and CuI (10 mg, 0.05 mmol, 0.03 equiv). The reaction vessel was purged with N_2, and the solution was stirred at 60 °C for 1 h. Upon completion, the crude mixture was passed through a silica plug (EtOAc elution) and concentrated under vacuum. The residue was purified by flash column chromatography (1:1 → 1:2 hex:EtOAc) to afford the sample of **58f** (63 mg, 19%) as a brown oil.

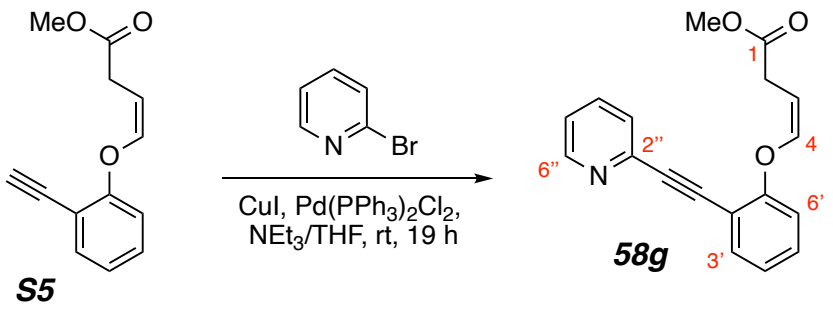
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.64 (ddd, *J* = 4.9, 1.9, 1.1 Hz, 1H, *H6'''*), 7.71 (ddd, *J* = 7.8, 7.8, 1.8 Hz, 1H, *H4'''*), 7.59 (ddd, *J* = 7.8, 1.2, 1.2 Hz, 1H, *H3'''*), 7.33 (ddd, *J* = 7.7, 4.9, 1.3 Hz, 1H, *H5'''*), 5.84 (ddt, *J* = 17.4, 9.9, 5.8 Hz, 1H, *H2'* or *H2''*), 5.77 (ddt, *J* = 17.4, 10.2, 5.9 Hz, 1H, *H2'* or *H2''*), 5.28–5.17 (overlapping m, 4H, H_a3', H_b3', H_a3'', H_b3''), 4.27 (ddd, *J* = 5.9, 1.5, 1.5 Hz, 2H, C1'CH_2 or C1''CH_2), and 4.07 (ddd, *J* = 5.9, 1.5, 1.5 Hz, 2H, C1'CH_2 or C1''CH_2).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 153.9, 150.5, 141.5, 136.4, 132.7, 132.0, 128.5, 124.3, 118.6, 118.3, 88.3, 80.3, 51.0, and 46.5.

IR (neat): 3081, 3013, 2984, 2927, 2224, 1629, 1463, 1413, 1273, and 1217 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{14}H_{15}N_2O^+$, 227.1179; found, 227.1173.

Methyl (*Z*)-4-(2-(Pyridin-2-ylethynyl)phenoxy)but-3-enoate (58g)



To a solution of 2-bromopyridine (23 µL, 0.24 mmol, 1.0 equiv) and **S5** (52 mg, 0.24 mmol, 1.0 equiv) in Et_3N (0.5 mL) and THF (0.5 mL) was added $Pd(PPh_3)_2Cl_2$ (3.4 mg, 0.005 mmol, 0.02 equiv) and CuI (2 mg, 0.01 mmol, 0.04 equiv). The head space of the vessel was purged with N_2, and the solution was stirred at room temperature for 19 h. Upon completion, the crude mixture was passed through a silica plug (EtOAc elution) and concentrated under vacuum. The residue was purified by MPLC (2:1 hex:EtOAc) to afford **58g** (25 mg, 35%) as a clear yellow oil.

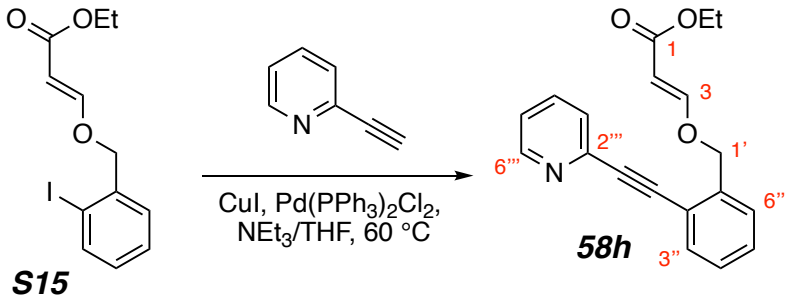
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.62 (ddd, *J* = 4.9, 1.9, 1.0 Hz, 1H, *H6"*), 7.68 (ddd, *J* = 7.7, 7.7, 1.8 Hz, 1H, *H4"*), 7.60 (dd, *J* = 7.7, 1.7 Hz, 1H, *H3'*), 7.56 (ddd, *J* = 7.9, 1.1, 1.1 Hz, 1H, *H3"*), 7.33 (ddd, *J* = 8.3, 7.5, 1.7 Hz, 1H, *H5'*), 7.24 (ddd, *J* = 7.6, 4.9, 1.2 Hz, 1H, *H5"*), 7.07 (ddd, *J* = 7.5, 7.5, 1.1 Hz, 1H, *H4'*), 7.01 (dd, *J* = 8.3, 1.2 Hz, 1H, *H6'*), 6.59 (dt, *J* = 6.0, 1.7 Hz, 1H, *H4*), 5.12 (td, *J* = 7.1, 5.9 Hz, 1H, *H3*), 3.68 (s, 3H, CO_2CH_3), and 3.40 (dd, *J* = 7.1, 1.7 Hz, 2H, *H2*).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 172.3, 157.8, 150.2, 143.7, 142.5, 136.2, 134.1, 130.5, 127.5, 123.1, 122.9, 115.5, 113.1, 104.6, 93.3, 85.0, 52.0, and 29.8.

IR (neat): 3076, 3056, 3028, 3002, 2951, 2223, 1736, 1580, 1490, 1461, 1273, 1242, 1166, 1113, and 1019 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{18}H_{16}NO_3^+$, 294.1125; found, 294.1147.

Ethyl (*E*)-3-((2-(Pyridin-2-ylethynyl)benzyl)oxy)acrylate (58h)



To a solution of 2-ethynylpyridine (166 µL, 1.6 mmol, 1.0 equiv) and ethyl (*E*)-3-((2-iodobenzyl)oxy)acrylate[25] (**S15**, 547 mg, 1.6 mmol, 1.0 equiv) in Et_3N (3 mL) and THF (3 mL) was added $Pd(PPh_3)_2Cl_2$ (23 mg, 0.033 mmol, 0.02 equiv) and CuI (13 mg, 0.068 mmol, 0.04 equiv). The reaction vessel was purged with N_2, and the solution was stirred at 60 °C for 2 h. Upon completion, the crude mixture was passed through a silica plug (EtOAc elution) and concentrated under vacuum. The residue was purified by flash column chromatography (2:1 hex:EtOAc) to afford **58h** (450 mg, 89%) as a yellow oil.

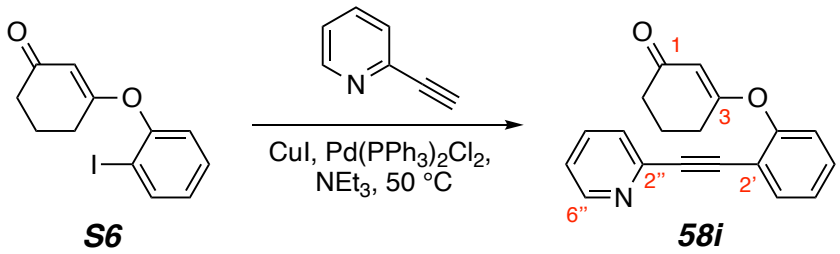
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.64 (ddd, *J* = 4.9, 1.9, 1.0 Hz, 1H, *H6'''*), 7.73 (d, *J* = 12.6 Hz, 1H, *H3*), 7.70 (ddd, *J* = 7.7, 7.7, 1.8 Hz, 1H, *H4'''*), 7.64 (ddd, *J* = 7.6, 1.5, 0.7 Hz, 1H, *H3''*), 7.53 (ddd, *J* = 7.8, 1.1, 1.1 Hz, 1H, *H3'''*), 7.46 (ddd, *J* = 7.7, 1.6, 0.7 Hz, 1H, *H6''*), 7.42 (ddd, *J* = 7.4, 7.4, 1.4 Hz, 1H, *H5''*), 7.35 (ddd, *J* = 7.5, 7.5, 1.6 Hz, 1H, *H4''*), 7.27 (ddd, *J* = 7.6, 4.9, 1.2 Hz, 1H, *H5'''*), 5.38 (d, *J* = 12.6 Hz, 1H, *H2*), 5.20 (s, 2H, C1'H_2), 4.16 (q, *J* = 7.1, 2H, OC$H_2$$CH_3$), and 1.26 (q, *J* = 7.1, 3H, OCH_2CH_3).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 167.7, 162.2, 150.3, 143.1, 137.5, 136.4, 132.9, 129.5, 128.5, 127.8, 127.5, 123.2, 121.1, 97.8, 93.9, 85.9, 71.2, 69.9, and 14.5.

IR (neat): 3054, 2979, 2937, 2903, 2220, 1702, 1621, 1580, 1488, 1122, and 1041 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H^+]: calcd for $C_{19}H_{18}NO_3^+$, 308.1281; found, 308.1274.

3-(2-(Pyridin-2-ylethynyl)phenoxy)cyclohex-2-en-1-one (58i)



S6 ***58i***

To a solution of 2-ethynylpyridine (0.24 mL, 2.4 mmol, 1.0 equiv) and **S6** (979 mg, 3.1 mmol, 1.3 equiv) in Et_3N (8 mL) and THF (6 mL) was added $Pd(PPh_3)_2Cl_2$ (22 mg, 0.032 mmol, 0.01 equiv) and CuI (12 mg, 0.063 mmol, 0.03 equiv). The reaction vessel was purged with N_2, and the solution was stirred at 50 °C overnight. The crude mixture was passed through a silica plug (EtOAc elution) and concentrated under vacuum. The residue was purified by flash column chromatography (1:1 hex:EtOAc) to afford **58i** (469 mg, 48%) as a green-brown crystalline solid.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.62 (ddd, *J* = 4.9, 1.9, 1.0 Hz, 1H, *H6"*), 7.67 (ddd, *J* = 7.8, 7.8, 1.8 Hz, 1H, *H4"*), 7.64 (dd, *J* = 7.8, 1.7 Hz, 1H, *H3'*), 7.43 (ddd, *J* = 7.8, 1.1, 1.1 Hz, 1H, *H3"*), 7.41 (ddd, *J* = 8.1, 7.5, 1.7 Hz, 1H, *H5'*), 7.28–7.24 (m, 2H, *H4' & H5"*), 7.12 (dd, *J* = 8.2, 1.2 Hz, 1H, *H6'*), 5.11 (t, *J* = 1.0 Hz, 1H, *H2*), 2.78 (td, *J* = 6.2, 1.0 Hz, 2H, *H6*), 2.36 (nfot, J_{app} = 6.6 Hz, 2H, *H4*), and 2.09 (nfo-quintet, J_{app} = 6.5 Hz, 2H, *H5*).

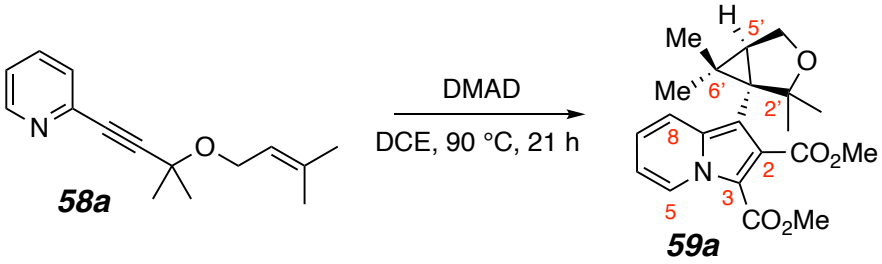
^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 199.8, 177.9, 153.9, 150.3, 143.2, 136.3, 134.1, 130.7, 127.2, 126.3, 123.2, 122.2, 116.5, 106.6, 94.0, 83.7, 36.8, 28.4, and 21.3.

IR (neat): 3057, 3004, 2949, 2890, 2871, 2829, 1651, 1614, 1579, 1486, 1371, 1206, 1155, and 1131 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{19}H_{16}NO_2^+$, 290.1176; found, 290.1198.

mp: 63–65 °C.

(±)-Dimethyl 1-((1*R*,5*R*)-2,2,6,6-Tetramethyl-3-oxabicyclo[3.1.0]hexan-1-yl)indolizine-2,3-dicarboxylate (59a)



A solution of **58a** (40 mg, 0.17 mmol, 1 equiv), DMAD (74 mg, 0.52 mmol, 3 equiv), and DCE (2 mL) was charged with 4 Å molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 90 °C for 21 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (5:1 hex:EtOAc) to afford **59a** (43 mg, 66%) as a white crystalline solid.

The ^{1}H NMR spectrum for this material suggested that the compound exists as a 6.2:1 ratio of slowly interconverting (on the NMR time scale) atropisomers.

major atropisomer:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.41 (ddd, *J* = 7.2, 1.0, 1.0, Hz, 1H, *H5*), 7.64 (ddd, *J* = 9.0, 1.2, 1.2 Hz, 1H, *H8*), 7.09 (ddd, *J* = 9.0, 6.7, 1.1 Hz, 1H, *H7*), 6.86 (ddd, *J* = 7.2, 6.6, 1.4 Hz, 1H, *H6)*, 4.24 (dd, *J* = 9.1, 3.5 Hz, 1H, C4'H_aH$_b$), 3.99 (d, *J* = 9.0, 1H, C4'H$_a$$H_b$), 3.92 (s, 3H, CO_2CH_3), 3.89 (s, 3H, CO_2CH_3), 1.74 (d, *J* = 3.4, 1H, *H5'*), 1.44 (s, 3H, C6'CH_3), 1.32 (s, 3H, C2'CH_3), 0.95 (s, 3H, C2'CH_3'), and 0.83 (s, 3H, C6'CH_3').

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 167.2, 160.9, 136.5, 128.5, 127.6, 122.3, 118.9, 113.9, 111.7, 111.1, 84.9, 65.1, 52.2, 51.7, 38.9, 34.8, 27.0, 25.79, 25.75, 22.9, and 16.3.

minor atropisomer:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.39 (ddd, *J* = 7.2, 1.1, 1.1, Hz, 1H, *H5*), 7.54 (ddd, *J* = 9.0, 1.2, 1.2 Hz, 1H, *H8*), 7.08 (ddd, *J* = 9.0, 6.7, 1.1 Hz, 1H, *H7*), 6.87 (ddd, *J* = 7.2, 6.7, 1.4 Hz, 1H, *H6)*, 4.07 (dd, *J* = 8.9, 3.4 Hz, 1H, C4'H_aH$_b$), 3.89 (d, *J* = 9.0, 1H, C4'H$_a$$H_b$), 1.71 (d, *J* = 3.4, 1H, *H5'*), 1.55 (s, 3H, C6'CH_3), 1.40 (s, 3H, C2'CH_3), 1.06 (s, 3H, C2'CH_3'), and 0.73 (s, 3H, C6'CH_3').

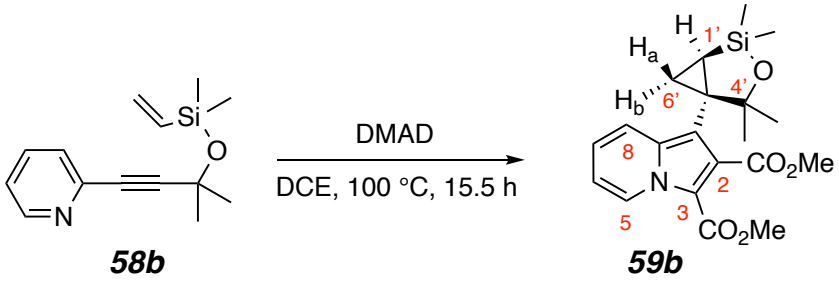
The following data are taken from the mixture of atropisomers:

IR (neat): 2970, 2949, 2910, 2869, 2849, 1735, 1687, 1494, 1438, 1371, 1205, 1161, 1116, and 1069 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{15}H_{20}NO^+$, 372.1805; found, 372.1836.

mp: 161–163 °C.

(±)-Dimethyl 1-((1*R*,5*S*)-2,2,4,4-Tetramethyl-3-oxa-2-silabicyclo[3.1.0]hexan-5-yl)indolizine-2,3-dicarboxylate (59b)



58b ***59b***

A solution of **58b** (40 mg, 0.16 mmol, 1.0 equiv), DMAD (70 mg, 0.49 mmol, 3.0 equiv), and DCE (2 mL) was charged with 4 Å molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, which was then heated at 100 °C for 15.5 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (5:1 hex:EtOAc) to afford **59b** (54 mg, 85%) as a white crystalline solid.

The ^{1}H NMR spectrum for this material indicated that the compound exists as a 1.9:1 ratio of slowly interconverting (on the NMR time scale) atropisomers.

major atropisomer:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.39 (ddd, *J* = 7.2, 1.2, 1.2 Hz, 1H, *H5*), 7.73 (ddd, *J* = 9.0, 1.3, 1.3 Hz, 1H, *H8*), 7.10 (ddd, *J* = 9.1, 6.7, 1.2 Hz, 1H, *H7*), 6.89–6.85 (overlapping m, 1H, *H6*), 3.94 (s, 3H, CO_2CH_3), 3.87 (s, 3H, CO_2CH_3'), 1.36 (s, 3H, C4'CH_3), 1.24 (s, 3H, C4'CH_3'), 1.02 (dd, *J* = 6.6, 3.6 Hz, 1H, *Ha6'*), 0.95 (dd, *J* = 10.4, 3.6 Hz, 1H, *Hb6'*), 0.81 (dd, *J* = 10.4, 6.6 Hz, 1H, *H1'*), 0.39 (s, 3H, SiCH_3), and 0.22 (s, 3H, SiCH_3').

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 167.7, 160.8, 136.6, 129.2, 127.5, 122.6, 119.0, 114.10, 113.8, 110.2, 81.4, 52.5, 51.7, 32.1, 29.8, 28.9, 13.4, 11.5, 1.2, and -2.4.

minor atropisomer:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.41 (ddd, *J* = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 7.70 (ddd, *J* = 9.0, 1.3, 1.3 Hz, 1H, *H8*), 7.11 (ddd, *J* = 9.2, 6.7, 1.2 Hz, 1H, *H7*), 6.89–6.85 (overlapping m, 1H, *H6*), 3.94 (s, 3H, CO_2CH_3), 3.88 (s, 3H, CO_2CH_3'), 1.32 (s, 3H, C4'CH_3), 1.27 (dd, *J* = 10.5, 4.2 Hz, 1H, *Hb6'*), 1.16 (s, 3H, C4'CH_3), 0.92 (dd, *J* = 6.7, 4.2 Hz, 1H, *Ha6'*), 0.52 (dd, *J* = 10.6, 6.6 Hz, 1H, *H1'*), 0.52 (s, 3H, SiCH_3), and 0.24 (s, 3H, SiCH_3').

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 167.6, 160.8, 136.8, 129.5, 127.6, 122.7, 118.6, 114.08, 113.7, 110.1, 81.9, 52.5, 51.7, 32.2, 29.8, 27.1, 13.6, 11.6, 1.7, and -2.3.

The following data are taken from the mixture of atropisomers:

IR (neat): 3120, 3056, 2975, 2951, 2902, 1738, 1691, 1438, 1386, 1252, 1211, 1175, and 1120 cm^{-1}.

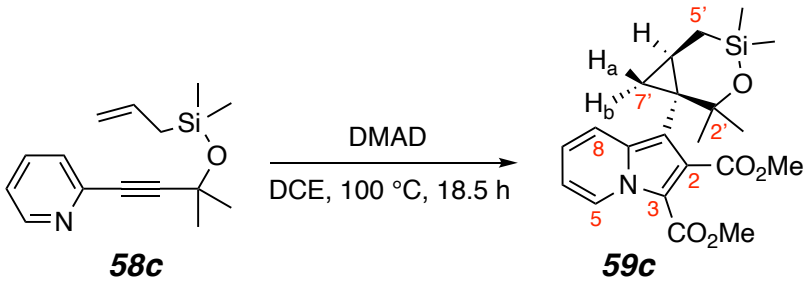
HRMS (ESI-TOF) *m/z* [$M+H^+$]: calcd for $C_{20}H_{26}NO_5Si^+$, 388.1575; found, 388.1602.

mp: 165–169 °C.

1 mmol scale reaction: 58b to 59b

The following experiment was performed to assess scalability: A solution of **58b** (265 mg, 1.1 mmol, 1 equiv), DMAD (454 mg, 3.2 mmol, 3 equiv), and DCE (10 mL) was charged with 4 Å molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, which was then heated at 100 °C for 17 h. The crude mixture was concentrated under vacuum, and the residue was purified using flash chromatography (4:1 → 3:1 hex:EtOAc) to afford **59b** (353 mg, 84%).

(±)-Dimethyl 1-((1*S*,6*R*)-2,2,4,4-Tetramethyl-3-oxa-4-silabicyclo[4.1.0]heptan-1-yl)indolizine-2,3-dicarboxylate (59c)



58c ***59c***

A solution of **58c** (40 mg, 0.15 mmol, 1.0 equiv), DMAD (66 mg, 0.46 mmol, 3.0 equiv), and DCE (2 mL) was charged with 4 Å molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 100 °C for 18.5 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (6:1 hex:EtOAc) to afford **59c** (48 mg, 78%) as a white crystalline solid.

The ^{1}H NMR spectrum for this material indicated that the compound exists as a 1.4:1 ratio of slowly interconverting (on the NMR time scale) atropisomers.

major atropisomer:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.37 (ddd, *J* = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 7.70 (ddd, *J* = 9.0, 1.3, 1.3 Hz, 1H, *H8*), 7.07 (ddd, *J* = 9.1, 6.7, 1.2 Hz, 1H, *H7*), 6.87–6.83 (overlapping m, 1H, *H6*), 3.96 (s, 3H, CO_2CH_3), 3.87 (s, 3H, CO_2CH_3'), 1.73 (dddd, *J* = 9.5, 6.3, 4.5, 3.3 Hz, 1H, *H4'*), 1.45–1.14 (overlapped multiplets, 3H, *H_a7',* C5'H_2), 1.39 (s, 3H, C2'CH_3), 1.21 (s, 3H, C2'CH_3), 0.73 (dd, *J* = 9.3, 4.5 Hz, 1H, *H_b7'*), 0.19 (s, 3H, SiCH_3), and 0.17 (s, 3H, SiCH_3').

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 167.8, 160.86, 136.7, 129.2, 127.5, 122.5, 119.5, 117.0, 114.0, 110.3, 75.8, 52.5, 51.64, 31.5, 29.2, 26.2, 20.1, 14.1, 10.1, 3.4, and 1.93.

minor atropisomer:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.39 (ddd, *J* = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 7.65 (ddd, *J* = 9.0, 1.3, 1.3 Hz, 1H, *H8*), 7.11 (ddd, *J* = 9.0, 6.7, 1.1 Hz, 1H, *H7*), 6.87–6.83 (overlapping m, 1H, *H6*), 3.92 (s, 3H, CO_2CH_3), 3.86 (s, 3H, CO_2CH_3'), 1.32 (s, 3H, C2'CH_3), 1.27 (s, 3H, C2'CH_3), 1.45–1.14 (overlapped multiplets, 5H, *H6'*, C5'H_2, C7'H_2), 0.21 (s, 3H, SiCH_3), and 0.20 (s, 3H, SiCH_3').

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 167.7, 160.87, 136.9, 129.6, 127.6, 122.3, 119.2, 116.8, 113.9, 110.4, 75.9, 52.4, 51.63, 30.7, 30.0, 26.3, 19.7, 14.3, 10.6, 3.5, and 1.91.

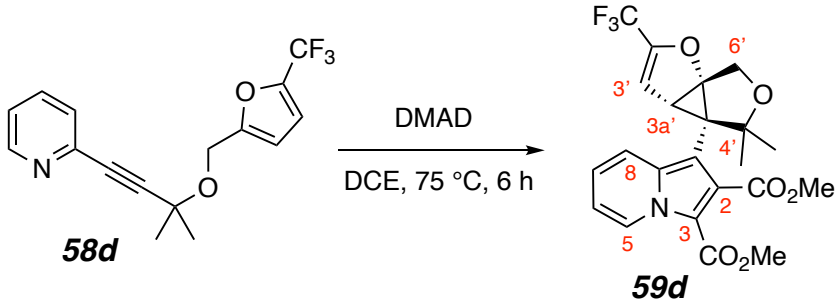
The following data are taken from the mixture of atropisomers:

IR (neat): 3118, 3076, 2971, 2951, 2897, 2884, 1737, 1687, 1494, 1438, 1384, 1361, 1253, 1206, 1178, 1145, 1122, and 1096 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H^{+}]: calcd for $C_{21}H_{28}NO_5Si^{+}$, 402.1731; found, 402.1762.

mp: 130–133 °C.

(±)-Dimethyl 1-((3a*S*,3b*S*,6a*S*)-4,4-Dimethyl-2-(trifluoromethyl)-4*H*,6*H*-cyclopropa[1,2-*b*:1,3-*c'*]difuran-3b(3a*H*)-yl)indolizine-2,3-dicarboxylate (59d)



A solution of **58d** (30 mg, 0.097 mmol, 1 equiv), DMAD (28 mg, 0.20 mmol, 2 equiv), and DCE (2 mL) was charged with 4 Å molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 75 °C for 6 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (3:1 hex:EtOAc) to afford **59d** (30 mg, 69%) as a white crystalline solid.

The ^{1}H NMR spectrum for this material suggested that the compound exists as a 14.1:1 ratio of slowly interconverting (on the NMR time scale) atropisomers.

major atropisomer:
^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.33 (ddd, *J* = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 7.56 (ddd, *J* = 9.1, 1.3, 1.3 Hz, 1H, *H8*), 7.08 (ddd, *J* = 9.1, 6.7, 1.1 Hz, 1H, *H7*), 6.83 (ddd, *J* = 7.1, 6.7, 1.4 Hz, 1H, *H6*), 5.77 (ddq, *J* = 2.6, 1.3, 1.3 Hz, 1H, *H3'*), 4.55 (ddd, *J* = 8.6, 1.2, 0.9 Hz, 1H, C6'*Ha*Hb), 4.26 (d, *J* = 8.6 Hz, 1H, C6'Ha*Hb*), 3.94 (s, 3H, C2CO_2CH_3), 3.88 (s, 3H, C3CO_2CH_3'), 2.79 (ddq, *J* = 2.4, 1.2, 1.2 Hz, 1H, *H3a'*), 1.27 (s, 3H, C4'CH_3), and 1.14 (s, 3H, C4'CH_3').

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 167.1 (C2CO_2CH$_3$), 160.6 (C3CO_2CH$_3$), 145.8 (*C*2', q, *J* = 39.8 Hz), 137.7 (*C*9), 128.5 (*C*2) 127.4 (*C*5), 122.7 (*C*7), 119.6 (*C*8), 117.9 (*C*F$_3$, q, *J* = 270 Hz), 114.1 (*C*6), 111.2 (*C*3), 110.1 (*C*3', q, *J* = 3.5 Hz), 104.7 (C1), 85.0 (*C*4'), 77.6 (*C*6'a), 63.4 (*C*6'), 52.4 (C2CO_2CH$_3$), 51.8 (C3CO_2CH$_3$), 33.1 (*C*3a'), 24.7, 23.4 (*C*3b', q, *J* = 1.3 Hz), and 22.8.

Partial data (^{1}H NMR) for the minor atropisomer:
^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.39 (ddd, *J* = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 7.59 (ddd, *J* = 9.0, 1.3, 1.3 Hz, 1H, *H8*), 7.11 (ddd, *J* = 9.0, 6.7, 1.1 Hz, 1H, *H7*), 6.91 (ddd, *J* = 7.2, 6.6, 1.4 Hz, 1H, *H6*), 5.49 (ddq, *J* = 2.7, 1.3, 1.3 Hz, 1H, *H3'*), 4.47 (ddd, *J* = 8.1, 1.1, 1.1 Hz, 1H, *H6'*), 4.14 (d, *J* = 8.1 Hz, 1H, *H6'*), 3.87 (s, 3H, CO_2CH_3), 3.85 (s, 3H, CO_2CH_3'), 2.88 (m, 1H, *H3a'*), 1.37 (s, 3H, C4'CH3), and 1.34 (s, 3H, C4'CH_3).

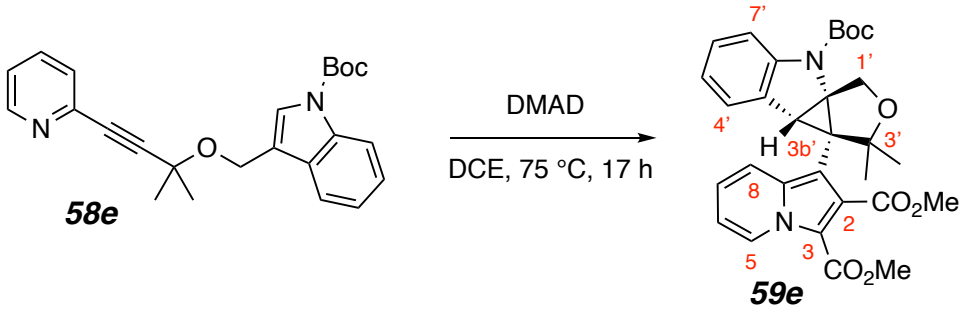
The following data are taken from the mixture of atropisomers:

IR (neat): 3123, 2977, 2952, 2869, 1735, 1693, 1504, 1378, 1217, 1179, 1139, and 1086 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{22}H_{21}F_3NO_6^+$, 452.1315; found, 452.1305.

mp: 118–121 °C.

(±)-Dimethyl 1-((3a*R*,8a*S*)-8-(*tert*-Butoxycarbonyl)-3,3-dimethyl-3b,8-dihydro-1*H*-furo[3',4':1,3]cyclopropa[1,2-*b*]indol-3a(3*H*)-yl)indolizine-2,3-dicarboxylate (59e)



58e ***59e***

A solution of **58e** (30 mg, 0.077 mmol, 1.0 equiv), DMAD (33 mg, 0.23 mmol, 3.0 equiv), and DCE (2 mL) was charged with 4 Å molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 75 °C for 17 h. The crude mixture was passed through a silica plug (EtOAc elution) and concentrated under vacuum. The residue was purified using MPLC (3:1 hex:EtOAc) to afford **59e** (16 mg, 39%) as a white crystalline solid.

The intermediate rate of rotation about the C1–C3a' bond rendered some of the resonances to appear as very broad, featureless peaks in the proton NMR spectrum.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.16 (broad d, *J* = 7.2 Hz, 1H, *H5*), 7.41 (broad m, *J* = 9.0 Hz, 1H, *H8*), 7.33 (dd, *J* = 7.5, 1.4 Hz, 1H, *H4'*), 7.18 (broad m, *J* = 7.6 Hz, 1H, *H7'*), 6.89 (broad dd, *J* = 7.2, 7.2 Hz, 1H, *H6'*), 6.84 (ddd, *J* = 8.9, 6.8, 0.6 Hz, 1H, *H7*), 6.77 (ddd, *J* = 7.5, 7.5, 1.0 Hz, 1H, *H5'*), 6.65 (ddd, *J* = 7.2, 6.7, 1.4 Hz, 1H, *H6*), 4.75 (dd, *J* = 8.7, 0.9 Hz, 1H, C1'H_aH_b), 4.69 (br s, 1H, *H3b'*). 4.32 (d, *J* = 8.7 Hz, 1H, C1'H_aH_b), 3.99 (broad s, 3H, C2CO_2CH_3), 3.82 (s, 3H, C3CO_2CH_3), 1.67–1.58 [two broad singlets, 9H, C(CH_3)$_3$], 1.55–1.43 (two broad singlets, 3H, C3'CH_3), and 1.13 (s, 3H, C3'CH_3').

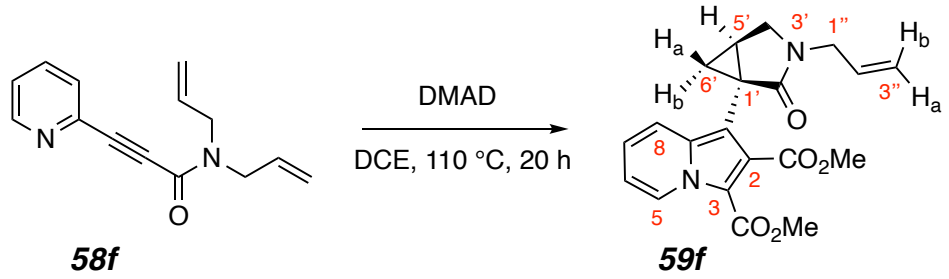
^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 166.0 (C2CO_2), 160.8 (C3CO_2), 153.0 (NCO_2), 142.7 (*C*7'a), 136.7 (*C*9), 130.9 (*C*3c'), 127.2 (br, 3 resonances from HMBC, *C*6', *C*5, and *C*2), 123.9 (*C*4'), 121.6 (C5'), 121.3 (*C*7), 119.7 (*C*8), 116.2 (C7'), 113.8 (C6), 111.3 (*C*3), 104.7 (C1), 86.3 (*C*3'), 82.4 (O*C*Me$_3$), 65.1 (*C*1'), 52.8 (C2CO_2CH_3), 51.7 (C3CO_2CH_3), 48.8 (*C*3b'), 43.0 (C8a'), 31.4 (*C*3a'), 28.6 [C(CH_3)$_3$], 25.2 [C3'(CH_3)$_a$(CH_3)$_b$], and 24.2 [C3'(CH_3)$_b$(CH_3)$_a$].

IR (neat): 2975, 2952, 2925, 2853, 1738, 1697, 1381, 1216, and 1154 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{30}H_{33}N_2O_7^+$, 533.2282; found, 533.2272.

mp: 118–123 °C.

(±)-Dimethyl 1-((1*S*,5*R*)-3-Allyl-2-oxo-3-azabicyclo[3.1.0]hexan-1-yl)indolizine-2,3-dicarboxylate (59f)



58f ***59f***

A solution of **58f** (25 mg, 0.11 mmol, 1.0 equiv), DMAD (47 mg, 0.33 mmol, 3.0 equiv), and DCE (2 mL) was charged with 4 Å molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 110 °C for 20 h. The crude mixture was passed through a silica plug (EtOAc elution) and concentrated under vacuum. The residue was purified using MPLC (1:1 → 1:2 hex:EtOAc) to afford **59f** (26 mg, 64%) as an off-white crystalline solid.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.35 (ddd, *J* = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 7.70 (ddd, *J* = 9.0, 1.3, 1.3 Hz, 1H, *H8*), 7.10 (ddd, *J* = 9.0, 6.7, 1.1 Hz, 1H, *H7*), 6.88 (ddd, *J* = 7.3, 6.6, 1.4 Hz, 1H, *H6*), 5.77–5.69 (nfom, 1H, *H2''*), 5.21 (dddd, *J* = 16.3, 1.5, 1.5, 1.5 Hz, 1H, H_b*3''*), 5.20 (dddd, *J* = 9.5, 1.4, 1.4, 1.4 Hz, 1H, H_a*3''*), 3.92 (s, 3H, C2CO_2CH_3), 3.88 (dddd, *J* = 15.2, 6.0, 1.4, 1.4 Hz, 1H, *H1''*), 3.87 (s, 3H, C3CO_2CH_3'), 3.82 (dddd, *J* = 15.2, 6.1, 1.4, 1.4 Hz, 1H, *H1''*), 3.62 (dd, *J* = 10.3, 5.7 Hz, 1H, *H4'*), 3.34 (d, *J* = 10.3 Hz, 1H, *H4'*), 2.11 (ddd, *J* = 7.9, 5.6, 4.3 Hz, 1H, *H5'*), 1.44 (dd, *J* = 7.8, 4.4 Hz, 1H, H_b*6'*), and 1.17 (dd, *J* = 4.4, 4.4 Hz, 1H, H_a*6'*).

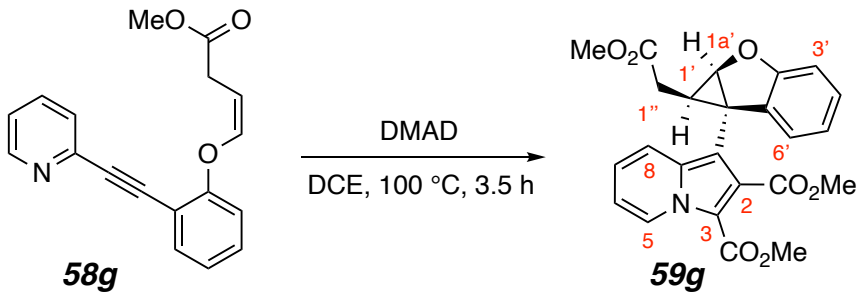
^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 173.6 (C2'), 166.9 (C2-*C*=O), 160.9 (C3-*C*=O), 137.0 (C9), 132.9 (C2''), 128.4 (C2), 127.5 (C5), 123.0 (C7), 118.3 (C8), 118.0 (C3''), 114.6 (C6), 110.6 (C3), 108.8 (C1), 52.6 (C2CO_2CH_3), 51.7 (C3CO_2CH_3), 47.7 (C4'), 45.4 (C1"), 26.1 (C1'), 19.1 (C6'), and 18.6 (C5'). These assignments are made aided by and are entirely consistent with the HSQC and HMBC data.

IR (neat): 3123, 3081, 2992, 2951, 2914, 2878, 1731, 1680, 1437, 1390, and 1205 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H^+]: calcd for $C_{20}H_{21}N_2O_5^+$, 369.1445; found, 369.1436.

mp: 116–119 °C.

(±)-Dimethyl 1-((1*R*,1a*R*,6b*S*)-1-(2-Methoxy-2-oxoethyl)-1,1a-dihydro-6b*H*-cyclopropa[*b*]benzofuran-6b-yl)indolizine-2,3-dicarboxylate (59g)



A solution of **58g** (19 mg, 0.065 mmol, 1 equiv), DMAD (29 mg, 0.20 mmol, 3 equiv), and DCE (1 mL) was charged with 4 Å molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 100 °C for 3.5 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (3:1 hex:EtOAc) to afford **59g** (18 mg, 64%) as a white crystalline solid.

The intermediate rate of rotation about the C1–C7' bond rendered some of the resonances to appear as very broad, featureless peaks in the proton NMR spectrum.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.41 (ddd, *J* = 7.2, 1.2, 1.2 Hz, 1H, *H5*), 7.85–7.37 (broad m, 1H, *H8*), 7.14 (ddd, *J* = 8.2, 7.5, 1.4 Hz, 1H, *H4'*), 7.07 (broad dd, *J* = 7, 7 Hz, 1H, *H7*), 7.07 (broad d, *J* = 7.3 Hz, 1H, *H6'*), 6.89 (ddd, *J* = 7.2, 6.7, 1.4 Hz, 1H, *H6*), 6.88 (ddd, *J* = 7.0, 0.9, 0.9 Hz, 1H, *H3'*), 6.84 (ddd, *J* = 7.4, 7.4, 1.0 Hz, 1H, *H5'*), 4.92 (d, *J* = 5.9 Hz, 1H, *H1a'*), 3.88 (s, 3H, CO_2CH_3), 3.84–3.75 (broad s, 3H, CO_2CH_3), 3.67 (s, 3H, C1'' CO_2CH_3), 2.15 (dd, *J* = 16.9, 5.8 Hz, 1H, C1"H_aH_b), 2.10–1.98 (broad m, 1H, C1"H_aH_b), and 1.94 (ddd, *J* = 6.9, 6.9, 5.9 Hz, 1H, *H1'*).

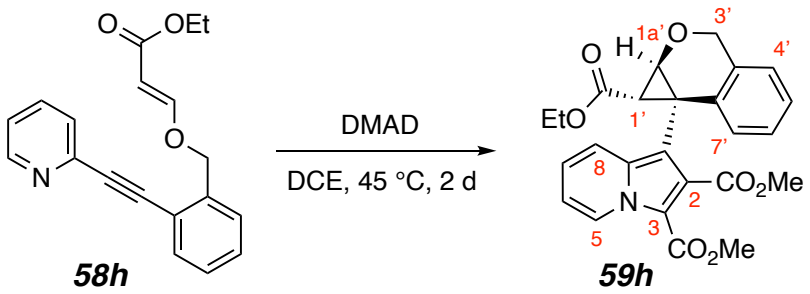
^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 172.9, 166.9, 160.9, 159.7, 136.0, 129.0, 128.8, 128.0, 127.6, 125.4, 123.2, 121.4, 118.0, 114.6, 110.7, 110.5, 109.4, 69.2, 52.6, 52.0, 51.7, 31.1, 27.1, and 17.4.

IR (neat): 3124, 3052, 2998, 2952, 2915, 2843, 1735, 1692, 1438, 1384, 1214, and 1174 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{24}H_{22}NO_7^+$, 436.1391; found, 436.1380.

mp: 132–134 °C.

(±)-Dimethyl 1-((1*S*,1a*R*,7b*R*)-1-(Ethoxycarbonyl)-1,1a-dihydrocyclopropa[*c*]isochromen-7b(3*H*)-yl)indolizine-2,3-dicarboxylate (59h)



58h ***59h***

A solution of **58h** (30 mg, 0.1 mmol, 1 equiv), DMAD (28 mg, 0.20 mmol, 2 equiv), and DCE (2 mL) was charged with 4 Å molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 45 °C for 2 d. The crude mixture was passed through a silica plug (EtOAc elution) and the eluant was concentrated under vacuum. The residue was initially purified using MPLC (2.5:1 hex:EtOAc). The sample was further purified by a recrystallization in which a boiling solution of 3:1 hex:EtOAc was slowly cooled to room temperature. The recrystallization afforded **59h** (27 mg, 62%) as a white crystalline solid.

The ^{1}H NMR spectrum for this material suggested that the compound exists as a 1.5:1 ratio of slowly interconverting (NMR time scale) atropisomers.

major atropisomer:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.42 (broad d, *J* = 7.1 Hz, 1H, H*5*), 7.65 (broad d, *J* = 9.0 Hz, 1H, H*8*), 7.15–7.08 (overlapping m, 4H, *H5'*, *H6'*, *H7'*, *H7'*), 7.06–6.99 (overlapping m, 1H, *H4'*), 6.92–6.85 (overlapping m, 1H, *H6*), 4.86 (d, *J* = 14.2 Hz, 1H, C3'H_aH_b), 4.83–4.77 (overlapping m, 1H, *H1a'*), 4.62 (d, *J* = 14.2 Hz, 1H, C3'H_aH_b), 3.88 (s, 3H, CO_2CH_3), 3.85 (s, 3H, CO_2CH_3'), 3.79 (dq, *J* = 11.0, 7.0 Hz, 1H, $CO_2CH_aH_b$), 3.72 (dq, *J* = 10.9, 7.1 Hz, 1H, $CO_2CH_aH_b$), 2.79 (d, *J* = 3.5 Hz, 1H, *H1'*), and 0.88 (t, *J* = 7.1 Hz, 3H, $CO_2CH_2CH_3$).

minor atropisomer:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.39 (broad d, *J* = 7.2 Hz, 1H, H*5*), 7.59 (broad d, *J* = 9.0 Hz, 1H, H*8*), 7.30 (broad d, *J* = 7.4 Hz, 1H, H*7'*), 7.15–7.08 (overlapping m, 2H, *H7* & *H5'* or *H6'*), 7.06–6.99 (overlapping m, 2H, *H4'* & *H5'* or *H6'*), 6.2–6.85 (overlapping m, 1H, *H6*), 4.86 (d, *J* = 14.2 Hz, 1H, C3'H_aH_b), 4.83–4.77 (overlapping m, 2H, *H1a'*, C3'H_aH_b), 4.09 (dq, *J* = 17.2, 7.1 Hz, 1H, $CO_2CH_aH_b$), 3.98 (dq, *J* = 17.2, 7.1 Hz, 1H, $CO_2CH_aH_b$), 3.90 (s, 3H, CO_2CH_3), 3.85 (s, 3H, CO_2CH_3'), 2.93 (d, *J* = 3.7 Hz, 1H, *H1'*), and 1.15 (t, *J* = 7.2 Hz, 3H, $CO_2CH_2CH_3$).

The following data are taken from the mixture of atropisomers:

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 169.1, 168.8, 166.5 (2x) 160.9, 160.5, 136.8, 135.8, 135.4, 134.8, 131.9, 130.0, 129.2, 128.4, 128.3, 127.9, 127.8 (2x), 127.7, 127.6, 126.7, 126.5, 125.3,

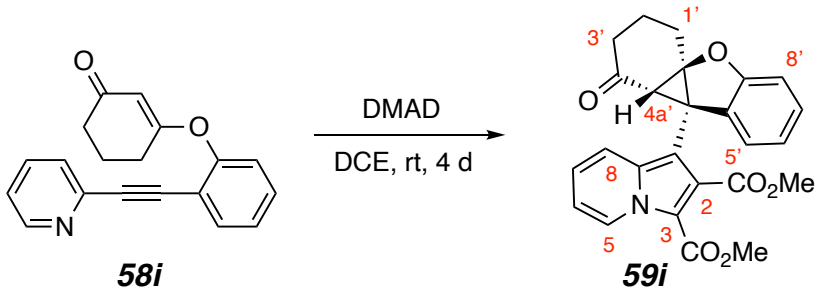
124.9, 123.0, 122.9, 118.1, 117.8, 114.6, 114.4, 110.3, 110.0, 67.3, 65.1, 64.83, 64.80, 61.1, 60.7, 52.7, 52.5, 51.70, 51.68, 33.0, 29.1, 27.6, 26.5, 14.0, and 13.9.

IR (neat): 3122, 3068, 2982, 2952, 2904, 2849, 2256, 1726, 1689, 1500, 1438, 1384, 1212, 1179, and 1120 cm^{-1}.

HRMS (ESI-TOF) *m/z* [$M+H^+$]: calcd for $C_{25}H_{24}NO_7^+$, 450.1547; found, 450.1536.

mp: 166–168 °C.

(±)-Dimethyl 1-((4a*S*,4b*S*,9a*R*)-4-Oxo-2,3,4,4a-tetrahydrobenzo[1,3]cyclopropa[1,2-*b*]benzofuran-4b(1*H*)-yl)indolizine-2,3-dicarboxylate (59i)



A solution of **58i** (20 mg, 0.07 mmol, 1.0 equiv), DMAD (29 mg, 0.20 mmol, 3.0 equiv), and DCE (1 mL) was charged with 4 Å molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and reacted at room temperature for 4 d. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (5:1 hex:EtOAc) to afford a pair of separable atropisomers **59i-maj** (16 mg, 54%) and **59i-min** (10 mg, 34%) each as a white crystalline solid. Heating each of these isolated isomers in $CDCl_3$ at 80 °C for 4 hours in attempts to interconvert the two led to multiple decomposition events as indicated by TLC and NMR analyses.

Data for the major atropisomer 59i-maj:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.40 (ddd, *J* = 7.3, 1.2, 1.2, Hz, 1H, *H5*), 7.74 (ddd, *J* = 9.0, 1.2, 1.2 Hz, 1H, *H8*), 7.17–7.13 (m, 2H, *H7* & *H7'*), 6.96–6.92 (m, 2H, *H6* & *H8'*), 6.82 (ddd, *J* = 7.5, 7.5, 1.0 Hz, 1H, *H6'*), 6.76 (ddd, *J* = 7.5, 1.5, 0.6 Hz, 1H, *H5'*), 3.86 (s, 3H, C3CO_2CH_3), 3.56 (s, 3H, C2CO_2CH_3), 2.68 (ddd, *J* = 14.4, 6.8, 5.5 Hz, 1H, C1'H_aH_b), 2.65 (ddd, *J* = 14.3, 8.1, 5.8 Hz, 1H, C1'H_aH_b), 2.11 (dddd, *J* =17.2, 9.0, 5.5, 1.2 Hz, 1H, C3'H_aH_b), 2.03 (d, *J* = 0.9 Hz, 1H, *H4a'*), 1.77 (ddddd, *J* = 13.9, 7.4, 6.7, 6.0, 5.3 Hz, 1H, C2'H_aH_b), 1.61 (dddd, *J* = 17.2, 7.2, 5.1, 1.2 Hz, 1H, C3'H_aH_b), and 1.52 (ddddd, *J* = 14.2, 8.8, 7.9, 5.5, 5.5 Hz, 1H C2'H_aH_b).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 206.8, 166.0, 160.8, 156.4, 135.7, 134.6, 128.2, 127.9, 127.4, 123.8, 123.4, 121.3, 118.4, 115.0, 112.2, 110.5, 107.2, 77.7, 52.4, 51.9, 40.5, 39.2, 38.0, 24.2, and 19.6.

IR (neat): 3122, 3049, 2995, 2951, 2889, 2871, 1733, 1689, 1504, 1439, 1389, 1213, and 1095 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{25}H_{22}NO_6^+$, 432.1442; found, 432.1476.

mp: 144–150 °C with decomposition.

Data for the minor atropisomer 59i-min:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.44 (ddd, *J* = 7.2, 1.2, 1.2, Hz, 1H, *H5*), 7.15 (ddd, *J* = 8.2, 7.4, 1.4 Hz, 1H, *H7'*), 7.12 (ddd, *J* = 9.0, 1.2, 1.2 Hz, 1H, *H8*), 7.09 (dd, *J* = 7.6, 1.5 Hz, 1H, *H5'*),

7.02 (ddd, *J* = 9.0, 6.7, 1.2 Hz, 1H, *H7*), 6.94 (ddd, *J* = 8.1, 0.8, 0.8 Hz, 1H, *H8′*), 6.91 (ddd, *J* = 7.2, 6.6, 1.4 Hz, 1H, *H6*), 6.84 (ddd, *J* = 7.5, 7.5, 1.0 Hz, 1H, *H6′*), 3.91 (s, 3H, CO_2CH_3), 3.90 (s, 3H, CO_2CH_3'), 2.72 (dddd, *J* = 14.4, 7.0, 6.0, 0.9 Hz, 1H, C1'H_aH_b), 2.51 (ddd, *J* = 14.6, 7.9, 5.3 Hz, 1H, C1'H_aH_b), 2.15 (ddddd, *J* = 16.8, 7.2, 4.9, 1.2, 1.2 Hz, 1H, C3'H_aH_b), 1.87 (d, *J* = 1.2 Hz, 1H, *H4a′*), 1.81 (ddd, *J* = 16.5, 8.8, 5.3 Hz, 1H, C3'H_aH_b), 1.72 (ddddd, *J* = 13.4, 8.8, 7.9, 6.0, 5.0 Hz, 1H, C2'H_aH_b), and 1.39 (ddddd, *J* = 13.0, 7.3, 7.3, 5.1, 5.1 Hz, 1H, C2'H_aH_b).

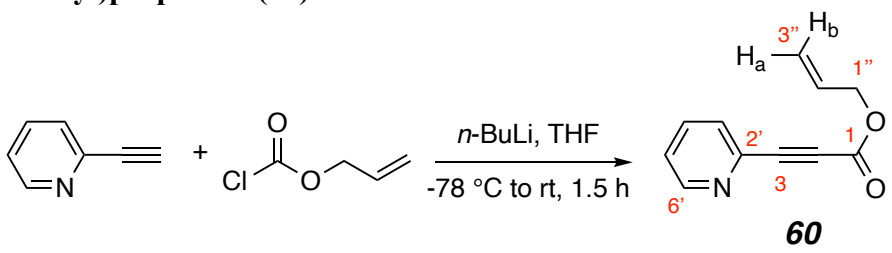
$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$): δ 205.2, 165.8, 161.0, 156.5, 135.8, 134.1, 128.4, 128.3, 127.9, 124.6, 123.6, 121.7, 117.8, 114.9, 111.3, 110.5, 107.2, 78.4, 53.1, 51.9, 40.5, 39.4, 37.6, 24.8, and 20.1.

IR (neat): 3122, 3031, 2952, 2868, 1733, 1690, 1505, 1390, 1222, and 1095 cm^{-1}.

HRMS (ESI-TOF) *m/z* [$M+H^+$]: calcd for $C_{25}H_{22}NO_6^+$, 432.1442; found, 432.1471.

mp: 156–161 °C with decomposition.

Allyl 3-(Pyridin-2-yl)propiolate (60)



60

To a solution of 2-ethynylpyridine (0.30 mL, 3.0 mmol, 1.0 equiv) in THF (6 mL) at -78 °C was added *n*-BuLi (1.32 mL, 3.3 mmol, 1.1 equiv; 2.5 M in THF) dropwise. After the solution was stirred for 30 min, allyl chloroformate (0.38 mL, 3.6 mmol, 1.2 equiv) was added dropwise. The mixture was stirred for 30 min at -78 °C and continued allowed to warm to room temperature over ca. 1 h. Water was added the crude product was extracted with EtOAc. The organic layer was washed with brine, dried with $MgSO_4$, and concentrated under vacuum. The resulting residue was purified by flash column chromatography (3:1 → 2:1 hex:EtOAc) to afford **60** (457 mg, 81%) as an orange oil.

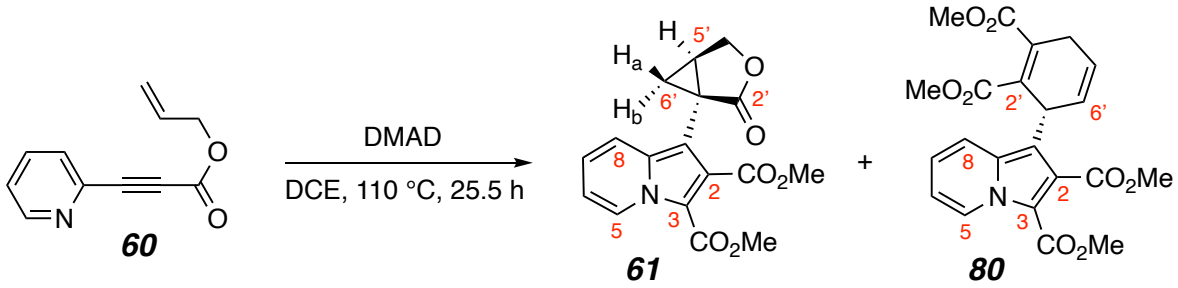
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.66 (ddd, *J* = 4.9, 1.8, 1.0 Hz, 1H, *H6'*), 7.73 (ddd, *J* = 7.7, 7.7, 1.8 Hz, 1H, *H4'*), 7.60 (ddd, *J* = 7.8, 1.1, 1.1 Hz, 1H, *H3'*), 7.36 (ddd, *J* = 7.7, 4.8, 1.2 Hz, 1H, *H5'*), 5.96 (ddt, *J* = 17.2, 10.5, 5.8 Hz, 1H, *H2"*), 5.41 (ddt, *J* = 17.2, 1.5, 1.5 Hz, 1H, H_b*3"*), 5.31 (ddt, *J* = 10.4, 1.2, 1.2 Hz, 1H, H_a*3"*), and 4.74 (ddd, *J* = 5.8, 1.4, 1.4 Hz, 2H, *H1"*).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 153.3, 150.7, 140.6, 136.5, 131.1, 128.7, 124.8, 119.5, 84.3, 79.0, and 66.8.

IR (neat): 3081, 3054, 2994, 2950, 2887, 2233, 1705, 1579, 1461, 1429, 1277, and 1107 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{11}H_{10}NO_2^+$, 188.0706; found, 188.0722.

(±)-Dimethyl 1-((1*S*,5*R*)-2-Oxo-3-oxabicyclo[3.1.0]hexan-1-yl)indolizine-2,3-dicarboxylate (61)
and
(±)-Dimethyl 1-(2,3-Bis(methoxycarbonyl)cyclohexa-2,5-dien-1-yl)indolizine-2,3-dicarboxylate (80)



A solution of **60** (40 mg, 0.21 mmol, 1.0 equiv), DMAD (91 mg, 0.64 mmol, 3.0 equiv), and DCE (2 mL) was charged with 4 Å molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 110 °C for 25.5 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (1:1 hex:EtOAc) to afford, in order of elution, **80** (7 mg, 9%) as a yellow oil and **61** (52 mg, 74%) as a yellow crystalline solid.

Data for 61

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.35 (ddd, *J* = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 7.65 (ddd, *J* = 9.0, 1.3, 1.3 Hz, 1H, *H8*), 7.14 (ddd, *J* = 9.0, 6.7, 1.1 Hz, 1H, *H7*), 6.91 (ddd, *J* = 7.2, 6.7, 1.4 Hz, 1H, *H6*), 4.50 (dd, *J* = 9.3, 4.7 Hz, 1H, C4'H_aHb), 4.33 (ddd, *J* = 9.3, 0.5, 0.5 Hz, 1H, C4'H$_a$*H$_b$*), 3.95 (s, 3H, CO_2CH_3), 3.88 (s, 3H, CO_2CH_3'), 2.46 (dddd, *J* = 7.8, 4.6, 4.6, 0.7 Hz, 1H, *H5'*), 1.64 (dd, *J* = 7.8, 4.6 Hz, 1H, *H$_b$6'*), and 1.48 (dd, *J* = 4.6, 4.6 Hz, 1H, *H$_a$6'*).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 175.6, 166.4, 160.8, 136.5, 127.9, 127.6, 123.5, 117.7, 114.7, 111.2, 106.4, 68.4, 52.7, 51.8, 24.0, 23.9, and 18.7.

IR (neat): 3125, 3090, 2996, 2954, 2907, 1766, 1730, 1690, 1506, 1439, 1393, 1279, 1215, and 1097 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{17}H_{16}NO_6^+$, 330.0972; found, 330.1002.

mp: 150–154 °C.

Data for 80

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.38 (ddd, *J* = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 7.43 (ddd, *J* = 9.1, 1.3, 1.3 Hz, 1H, *H8*), 7.07 (ddd, *J* = 9.0, 6.7, 1.1 Hz, 1H, *H7*), 6.87 (ddd, *J* = 7.2, 6.7, 1.4 Hz, 1H, *H6*), 5.83 (dddd, *J* = 10.0, 3.7, 3.1, 2.0 Hz, 1H, *H5'*), 5.72 (dddd, *J* = 10.1, 3.6, 2.3, 1.8 Hz, 1H,

H6'), 4.76 (dddd, *J* = 8.3, 8.3, 3.5, 2.0 Hz, 1H, *H1'*), 3.92 (s, 3H, CO_2CH_3), 3.86 (s, 3H, CO_2CH_3), 3.77 (s, 3H, CO_2CH_3), 3.50 (s, 3H, C2'CO_2CH_3), 3.27 (dddd, *J* = 23.5, 8.4, 3.2, 2.3 Hz, 1H, *H4'*), and 3.06 (dddd, *J* = 23.5, 8.3, 3.7, 1.8 Hz, 1H, *H4'*).

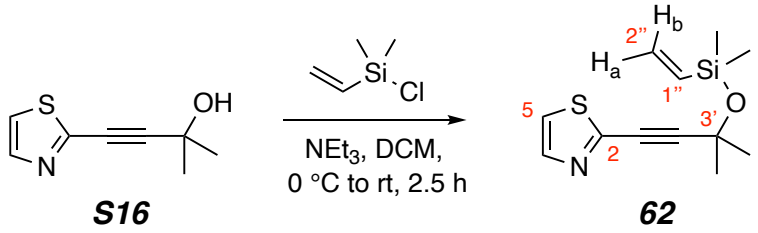
The notably large allylic-allylic coupling constants in a 1,4-cyclohexadiene (five-bond: here *J* = 8.4 Hz) were first described by Garbisch.[26]

$^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$): δ 168.1, 167.8, 166.8, 160.9, 134.9, 131.4, 129.2, 128.4, 127.6, 127.4, 126.0, 122.8, 121.5, 117.9, 114.3, 112.5, 52.6, 52.5, 52.2, 51.7, 34.6, and 27.6.

IR (neat): 3076, 2997, 2949, 2901, 1732, 1688, 1478, 1382, 1211, and 1090 cm^{-1}.

HRMS (ESI-TOF) *m/z* [$M+H^+$]: calcd for $C_{22}H_{22}NO_8^+$, 428.1340; found, 428.1382.

2-(3-((Dimethyl(vinyl)silyl)oxy)-3-methylbut-1-yn-1-yl)thiazole (62)



S16 ***62***

To a solution of 2-methyl-4-(thiazol-2-yl)but-3-yn-2-ol[28] (**S16**, 155 mg, 0.93 mmol, 1.0 equiv) in DCM (5 mL) was added NEt_3 (0.26 mL, 1.86 mmol, 2.0 equiv) and chloro(dimethyl)vinylsilane (0.19 mL, 1.38 mmol, 1.5 equiv) under N_2 at 0 °C. The solution was warmed to room temperature and stirred for 2.5 h. Water was added and the crude product was extracted with DCM. The organic layer was washed with brine, dried with $MgSO_4$, and concentrated under vacuum. The resulting residue was purified by a silica plug (1:1 hex:EtOAc) to afford **62** (140 mg, 60%) as a clear colorless oil.

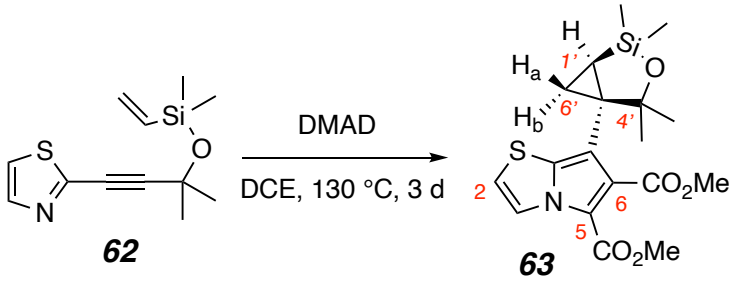
^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.82 (d, *J* = 3.3 Hz, 1H, *H4*), 7.34 (d, *J* = 3.3 Hz, 1H, *H5*), 6.27 (dd, *J* = 20.4, 14.8 Hz, 1H, *H1"*), 5.99 (dd, *J* = 14.8, 3.7 Hz, 1H, *H_a2"*), 5.79 (dd, *J* = 20.4, 3.7 Hz, 1H, *H_b2"*), 1.61 [s, 6H, C3'(CH_3)$_2$], and 0.31 [s, 6H, Si(CH_3)$_2$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 148.7, 143.6, 139.1, 132.5, 120.7, 99.2, 76.6, 67.3, 32.6, and 0.2.

IR (neat): 3116, 3084, 3051, 2985, 2966, 2331, 1479, 1405, 1250, and 1029 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H^+]: calcd for $C_{12}H_{18}NOSSi^+$, 252.0873; found, 252.0875.

(±)-Dimethyl 7-((1*R*,5*S*)-2,2,4,4-Tetramethyl-3-oxa-2-silabicyclo[3.1.0]hexan-5-yl)pyrrolo[2,1-*b*]thiazole-5,6-dicarboxylate (63)



62 **63**

A solution of **62** (30 mg, 0.12 mmol, 1.0 equiv), DMAD (51 mg, 0.36 mmol, 3.0 equiv), and DCE (2 mL) was charged with 4 Å molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 130 °C for 3 d. The crude mixture was passed through a silica plug (EtOAc elution) and concentrated under vacuum. The residue was purified using MPLC (3:1 hex:EtOAc) to afford **63** (31 mg, 66%) as an off-white crystalline solid.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.30 (d, *J* = 4.4 Hz, 1H, *H3*), 6.92 (d, *J* = 4.4 Hz, 1H, *H2*), 3.92 (s, 3H, CO_2CH_3), 3.86 (s, 3H, CO_2CH_3'), 1.32 (broad s, 3H, C4'CH_3), 1.29–1.23 (overlapping m, 4H, *H1'*, C4'CH_3'), 0.99–0.80 (broad m, 2H, C6'H_aH$_b$, C6'H$_a$$H_b$), 0.54–0.32 (broad s, 3H, SiCH_3), and 0.20 (s, 3H, SiCH_3').

^{1}H-NMR (500 MHz, DMSO-d_6, spectrum recorded at 110 °C): δ 8.24 (d, *J* = 4.2 Hz, 1H, *H3*), 7.41 (d, *J* = 4.2 Hz, 1H, *H2*), 3.83 (s, 3H, CO_2CH_3), 3.82 (s, 3H, CO_2CH_3'), 1.25 (s, 3H, C4'CH_3), 1.18 (s, 3H, C4'CH_3'), 1.00 (dd, *J* = 10.4, 3.6 Hz, 1H, *H$_b$6'*), 0.86 (dd, *J* = 6.7, 3.8 Hz, 1H, *H$_a$6'*), 0.64 (dd, *J* = 10.3, 6.9 Hz, 1H, *H1'*), 0.37 (s, 3H, SiCH_3), and 0.14 (s, 3H, SiCH_3').

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 166.5, 160.1, 137.8 (br, C5 or C8), 128.4 (br, C5 or C6), 123.1 (C3), 114.2 (C2), 114.1 (br, C5 or C8), 112.2 (C5 or C6), 82.0 (br), 52.5, 51.8, 33.1 (C5'), 29.8 (C4'CH_3'), 29.7 (br, C4'CH_3'), 28.9 (br, C4'CH_3) 26.9 (br, C4'CH_3), 15.1 (br), 14.2, 13.3 (br, C1'), 12.4 (br), 10.7 (br, C1'), 1.3 (br, SiCH_3), and -2.4 (SiCH_3').

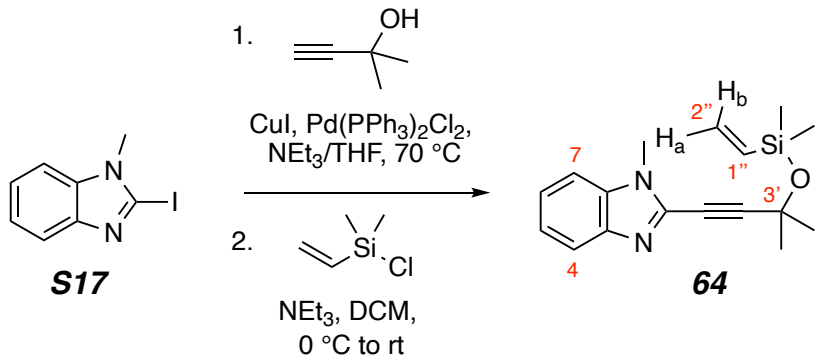
This compound also showed some surprisingly long-range HMBC correlations. To check the viability of this phenomenon and interpretation, we prepared the model thiazole-derived adduct **71**, the HMBC spectrum of which showed a similar behavior.

IR (neat): 3150, 3118, 2974, 2952, 2901, 1735, 1696, 1490, 1441, 1377, 1223, and 1123 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{18}H_{24}NO_5SSi^+$, 394.1139; found, 394.1143.

mp: 134–139 °C.

2-(3-((Dimethyl(vinyl)silyl)oxy)-3-methylbut-1-yn-1-yl)-1-methyl-1*H*-benzo[*d*]imidazole (64)



To a solution of 2-iodo-1-methyl-1*H*-benzo[*d*]imidazole[27] (**S17**, 456 mg, 1.76 mmol, 1 equiv) and 2-methylbut-3-yn-2-ol (205 µL, 2.1 mmol, 1.2 equiv) in Et_3N (3 mL) and THF (3 mL) was added $Pd(PPh_3)_2Cl_2$ (24 mg, 0.034 mmol, 0.02 equiv) and CuI (13 mg, 0.068 mmol, 0.04 equiv). The reaction vessel was purged with N_2, and the solution was stirred at 70 °C for 3 h. The crude mixture was passed through a silica plug (EtOAc elution) and concentrated under vacuum. The residue was dissolved in DCM (10 mL) and NEt_3 (0.74 mL, 5.3 mmol, 3 equiv) and chloro(dimethyl)vinylsilane (0.49 mL, 3.5 mmol, 2.0 equiv) was added. The solution was stirred under N_2 at 0 °C and then warmed to room temperature and stirred for 1 h. Water was added and the crude product was extracted with DCM. The organic layer was washed with brine, dried with $MgSO_4$, and concentrated under vacuum. The resulting residue was purified by flash column chromatography (4.5:1 hex:EtOAc) to afford **64** (443 mg, 84%) as a white crystalline solid.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.76 (ddd, *J* = 7.9, 1.1, 1.1 Hz, 1H, *H7*), 7.36–7.27 (m, 3H, *H4, H5, H6*), 6.28 (dd, *J* = 20.5, 14.8 Hz, 1H, *H1"*), 5.98 (dd, *J* = 14.8, 3.7 Hz, 1H, *H2"$_a$*), 5.79 (dd, *J* = 20.4, 3.7 Hz, 1H, *H2"$_b$*), 3.85 (s, 3H, N-C*H*$_3$), 1.67 [s, 6H, C3'(C*H*$_3$)$_2$], and 0.32 [s, 6H, Si(C*H*$_3$)$_2$].

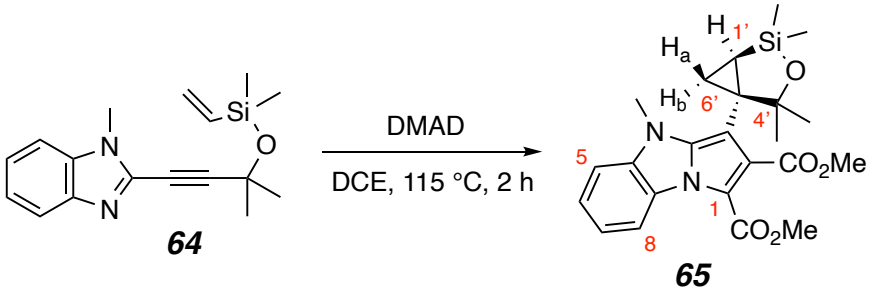
^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 143.0, 139.2, 137.3, 134.9, 132.6, 124.0, 123.0, 120.4, 109.5, 100.3, 73.1, 67.4, 32.8, 30.8, and 0.3.

IR (neat): 3062, 2984, 2946, 2934, 1609, 1593, 1454, 1384, 1330, 1250, 1153, and 1032 cm^{-1}.

mp: 58–59 °C.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{17}H_{23}N_2OSi^+$, 299.1574; found, 299.1572.

(±)-Dimethyl 4-Methyl-3-((1*R*,5*S*)-2,2,4,4-tetramethyl-3-oxa-2-silabicyclo[3.1.0]hexan-5-yl)-4*H*-benzo[*d*]pyrrolo[1,2-*a*]imidazole-1,2-dicarboxylate (65)



64 ***65***

A solution of **64** (30 mg, 0.10 mmol, 1 equiv), DMAD (43 mg, 0.30 mmol, 3 equiv), and DCE (2 mL) was charged with 4 Å molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 115 °C for 2 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (3:1 hex:EtOAc) to afford **65** (40 mg, 90%) as an off-white crystalline solid.

The ^{1}H NMR spectrum for this material suggested that the compound exists as a 3.3:1 ratio of slowly interconverting (on the NMR time scale) atropisomers.

major atropisomer:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.76 (ddd, *J* = 8.2, 1.1, 0.6 Hz, 1H, *H8*), 7.35 (ddd, *J* = 8.3, 7.3, 1.2 Hz, 1H, *H6* or *H7*), 7.24–7.19 (overlapping m, 2H, *H5, & H6* or *H7*), 3.97 (s, 3H, N-CH_3), 3.92 (s, 3H, CO_2CH_3), 3.87 (s, 3H, CO_2CH_3'), 1.41 (s, 3H, C4'CH_3), 1.31 (s, 3H, C4'CH_3'), 1.11 (dd, *J* = 10.5, 3.2 Hz, 1H, *H_b6'*), 1.04 (dd, *J* = 6.5, 3.2 Hz, 1H, *H_a6'*), 0.96 (dd, *J* = 10.5, 6.5 Hz, 1H, *H1'*), 0.40 (s, 3H, SiCH_3), and 0.21 (s, 3H, SiCH_3').

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 167.53, 160.27, 140.6, 137.8, 131.4, 127.0, 124.31, 120.6, 116.36, 108.6, 106.80, 97.1, 80.9, 52.4, 51.54, 31.7, 31.0, 30.0, 28.8, 15.7, 12.9, 1.1, and -2.4.

minor atropisomer:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.77 (ddd, *J* = 8.3, 1.1, 0.7 Hz, 1H, *H8*), 7.37–7.34 (overlapping m, 1H, *H6* or *H7*), 7.24–7.19 (overlapping m, 2H, *H5, & H6* or *H7*), 4.01 (s, 3H, N-CH_3), 3.92 (s, 3H, CO_2CH_3), 3.88 (s, 3H, CO_2CH_3'), 1.48 (dd, *J* = 10.7, 4.3 Hz, 1H, *H_b6'*), 1.33 (s, 3H, C4'CH_3), 1.30 (s, 3H, C4'CH_3'), 0.93 (dd, *J* = 6.5, 4.2 Hz, 1H, *H_a6'*), 0.57 (dd, *J* = 10.7, 6.5 Hz, 1H, *H1'*), 0.44 (s, 3H, SiCH_3), and 0.23 (s, 3H, SiCH_3').

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 167.46, 160.25, 140.5, 137.6, 131.8, 126.9, 124.32, 120.7, 116.43, 108.5, 106.77, 97.2, 82.1, 52.3, 51.55, 32.0, 31.9, 29.8, 27.4, 15.3, 13.9, 1.7, and -1.9.

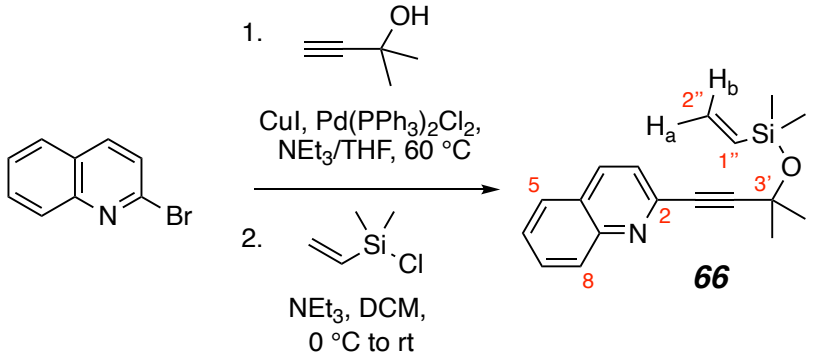
The following data are taken from the mixture of atropisomers:

IR (neat): 3060, 2975, 2949, 2904, 2851, 1733, 1692, 1578, 1488, 1438, 1391, 1371, 1333, 1283, 1204, 1146, 1133, 1093, and 1075 cm^{-1}.

mp: 161–164 °C.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{23}H_{29}N_2O_5Si^+$, 441.1840; found, 441.1842.

2-(3-((Dimethyl(vinyl)silyl)oxy)-3-methylbut-1-yn-1-yl)quinoline (66)



To a solution of 2-bromoquinoline (411 mg, 2.0 mmol, 1 equiv) and 2-methylbut-3-yn-2-ol (0.23 mL, 2.3 mmol, 1.2 equiv) in Et_3N (3 mL) and THF (3 mL) was added $Pd(PPh_3)_2Cl_2$ (27 mg, 0.038 mmol, 0.02 equiv) and CuI (14 mg, 0.074 mmol, 0.04 equiv). The reaction vessel was purged with N_2, and the solution was stirred at 60 °C for 1 h. The crude mixture was passed through a silica plug (EtOAc elution) and concentrated under vacuum. The residue was dissolved in DCM (10 mL) and NEt_3 (0.82 mL, 5.9 mmol, 3 equiv) and chloro(dimethyl)vinylsilane (0.55 mL, 4.0 mmol, 2.0 equiv) was added to the solution under N_2 at 0 °C. The solution was warmed to room temperature and stirred for 1 h. Water was added and the crude product was extracted with DCM. The organic layer was washed with brine, dried with $MgSO_4$, and concentrated under vacuum. The resulting residue was purified by flash column chromatography (6:1 hex:EtOAc) to afford **66** (525 mg, 90%) as a yellow oil.

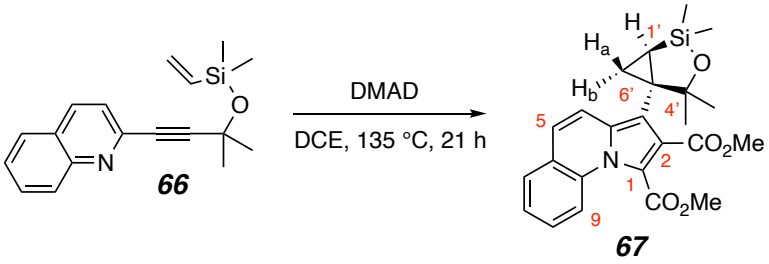
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.12–8.09 (m, 2H, *H4* & *H8*), 7.79 (dd, *J* = 8.2, 1.4 Hz, 1H, *H5*), 7.72 (ddd, *J* = 8.4, 6.7, 1.4 Hz, 1H, *H7*), 7.54 (ddd, *J* = 8.0, 6.9, 1.1 Hz, 1H, *H6*), 7.48 (d, *J* = 8.4 Hz, 1H, *H3*), 6.33 (dd, *J* = 20.5, 14.8 Hz, 1H, *H1"*), 5.99 (dd, *J* = 14.8, 3.7 Hz, 1H, *H2"a*), 5.81 (dd, *J* = 20.5, 3.7 Hz, 1H, *H2"b*), 1.66 [s, 6H, C3'(CH_3)$_2$], and 0.34 [s, 6H, Si(CH_3)$_2$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 148.3, 143.5, 139.5, 136.2, 132.2, 130.1, 129.5, 127.6, 127.3, 127.2, 124.2, 95.2, 83.3, 67.4, 32.9, and 0.3.

IR (neat): 3052, 2983, 2936, 2902, 2255, 2224, 1593, 1499, 1423, 1277, 1246, 1156, and 1029 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{18}H_{22}NOSi^+$, 296.1465; found, 296.1463.

(±)-Dimethyl 3-((1*R*,5*S*)-2,2,4,4-Tetramethyl-3-oxa-2-silabicyclo[3.1.0]hexan-5-yl)pyrrolo[1,2-*a*]quinoline-1,2-dicarboxylate (67)



A solution of **66** (30 mg, 0.10 mmol, 1 equiv), DMAD (72 mg, 0.51 mmol, 5 equiv), and DCE (1.5 mL) was charged with 4 Å molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 135 °C for 21 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (4.5:1 hex:EtOAc) to afford **67** (34 mg, 77%) as a white crystalline solid.

The ^{1}H NMR spectrum for this material suggested that the compound exists as a 3:1 ratio of slowly interconverting (on the NMR time scale) atropisomers.

major atropisomer:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.90 (dddd, *J* = 8.6, 0.9, 0.9, 0.9 Hz, 1H, *H9*), 7.69 (dd, *J* = 7.8, 1.6 Hz, 1H, *H6*), 7.62 (d, *J* = 9.5 Hz, 1H, *H5*), 7.50 (ddd, *J* = 8.7, 7.2, 1.6 Hz, 1H, *H8*), 7.41 (ddd, *J* = 7.8, 7.2, 1.1 Hz, 1H, *H7*), 7.26–7.24 (overlapping m, 1H, *H4*), 3.99 (s, 3H, CO_2CH_3), 3.90 (s, 3H, CO_2CH_3'), 1.33 (s, 3H, C4'CH_3), 1.26 (s, 3H, C4'CH_3'), 1.07 (dd, *J* = 6.7, 3.6 Hz, 1H, *Ha6'*), 1.00 (dd, *J* = 10.4, 3.6 Hz, 1H, *Hb6'*), 0.78 (dd, *J* = 10.4, 6.7 Hz, 1H, *H1'*), 0.45 (s, 3H, SiCH_3), and 0.22 (s, 3H, SiCH_3').

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 166.1, 163.6, 134.4, 133.19, 128.9, 128.2, 126.0, 125.57, 125.3, 123.2, 119.1, 118.2, 118.1, 116.8, 81.7, 52.8, 52.3, 31.9, 29.2, 28.5, 14.2, 11.8, 1.2, and -2.24.

minor atropisomer:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.89 (ddd, *J* = 8.7, 0.9, 0.9, 0.9 Hz, 1H, *H9*), 7.70–7.68 (overlapping m, 1H, *H6*), 7.60 (d, *J* = 9.4 Hz, 1H, *H5*), 7.52–7.48 (overlapping m, 1H, *H8*), 7.43–7.39 (overlapping m, 1H, *H7*), 7.26 (d, *J* = 9.4 Hz, 1H, *H4*), 4.01 (s, 3H, CO_2CH_3), 3.91 (s, 3H, CO_2CH_3'), 1.32 (s, 3H, C4'CH_3), 1.23 (dd, *J* = 10.4, 4.4 Hz, 1H, *Hb6'*), 1.17 (s, 3H, C4'CH_3'), 1.03 (dd, *J* = 6.7, 4.5 Hz, 1H, *Ha6'*), 0.60 (dd, *J* = 10.4, 6.7 Hz, 1H, *H1'*), 0.54 (s, 3H, SiCH_3), and 0.25 (s, 3H, SiCH_3').

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 166.1 (overlapping), 163.8, 134.1, 133.17, 129.0, 128.3, 125.63, 125.5, 125.4, 123.1, 119.5, 118.0, 117.7, 116.6, 82.0, 52.9, 52.1, 31.8, 30.0, 27.5, 14.3, 12.8, 1.8, and -2.23.

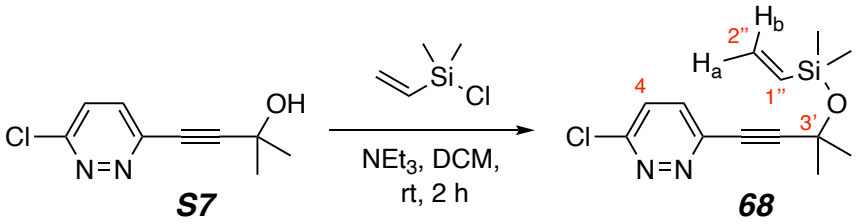
The following data are taken from the mixture of atropisomers:

IR (neat): 3055, 2975, 2951, 2904, 1725, 1492, 1447, 1251, 1206, and 1176 cm^{-1}.

mp: 166–170 °C.

HRMS (ESI-TOF) *m/z* [M+H^{+}]: calcd for $C_{24}H_{28}NO_5Si^{+}$, 438.1731; found, 438.1733.

3-Chloro-6-(3-((dimethyl(vinyl)silyl)oxy)-3-methylbut-1-yn-1-yl)pyridazine (68)



To a solution of 4-(6-chloropyridazin-3-yl)-2-methylbut-3-yn-2-ol (**S7**, 242 mg, 1.2 mmol, 1 equiv) in DCM (7 mL) was added NEt_3 (0.52 mL, 0.37 mmol, 3 equiv) and chloro(dimethyl)vinylsilane (0.37 mL, 2.7 mmol, 2.2 equiv). The solution was stirred at room temperature for 2 h. Water was added and the crude product was extracted with DCM. The organic layer was washed with brine, dried with $MgSO_4$, and concentrated under vacuum. The resulting residue was purified by flash column chromatography (5:1 hex:EtOAc) to afford **68** (291 mg, 84%) as a yellow oil.

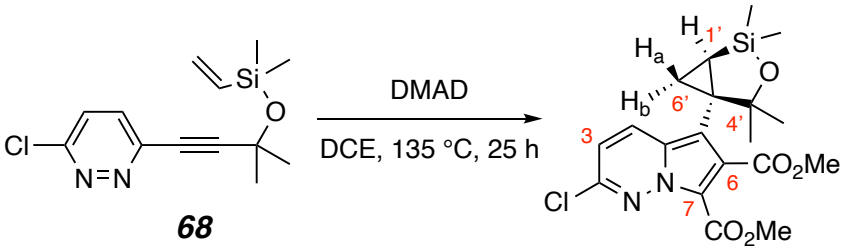
^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.49 (d, *J* = 8.9 Hz, 1H, *H4* or *H5*), 7.46 (d, *J* = 8.8 Hz, 1H, *H4* or *H5*), 6.28 (dd, *J* = 20.5, 14.8 Hz, 1H, *H1"*), 5.98 (dd, *J* = 14.8, 3.7 Hz, 1H, *H2"a*), 5.79 (dd, *J* = 20.5, 3.7 Hz, 1H, *H2"b*), 1.63 [s, 6H, C3'(CH_3)$_2$], and 0.30 [s, 6H, Si(CH_3)$_2$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 155.2, 147.0, 139.2, 132.5, 131.4, 127.7, 100.6, 78.9, 67.3, 32.6, and 0.2.

IR (neat): 3050, 2985, 2966, 2243, 1524, 1393, 1265, 1251, 1160, 1134, and 1032 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{13}H_{18}{}^{35}ClN_2OSi^+$, 281.0871; found, 281.0863.

(±)-Dimethyl 2-Chloro-5-((1*R*,5*S*)-2,2,4,4-tetramethyl-3-oxa-2-silabicyclo[3.1.0]hexan-5-yl)pyrrolo[1,2-*b*]pyridazine-6,7-dicarboxylate (69)



68 ***69***

A solution of **68** (30 mg, 0.11 mmol, 1 equiv), DMAD (137 mg, 0.96 mmol, 9 equiv), and DCE (1.0 mL) was charged with 4 Å molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 135 °C for 25 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (3:1 hex:EtOAc) to afford **69** (30 mg, 66%) as a yellow oil.

The ^{1}H NMR spectrum for this material suggested that the compound exists as a 2.1:1 ratio of slowly interconverting (on the NMR time scale) atropisomers.

major atropisomer:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.99 (d, *J* = 9.5 Hz, 1H, *H3* or *H4*), 6.84 (d, *J* = 9.5 Hz, 1H, *H3* or *H4*), 3.95 (s, 3H, CO_2CH_3), 3.92 (s, 3H, CO_2CH_3'), 1.29 (s, 3H, C4'CH_3), 1.20 (s, 3H, C4'CH_3'), 1.00 (dd, *J* = 6.6, 3.4 Hz, 1H, *H*$_a$*6'*), 0.90 (dd, *J* = 10.5, 3.4 Hz, 1H, *H*$_b$*6'*), 0.83 (dd, *J* = 10.5, 6.6 Hz, 1H, *H1'*), 0.41 (s, 3H, SiCH_3), and 0.22 (s, 3H, SiCH_3').

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 165.79, 159.5, 148.21, 129.0, 127.4, 125.8, 118.18, 115.57, 115.56, 81.1, 52.6, 52.4, 31.9, 29.3, 28.3, 13.5, 11.4, 1.1, and -2.5.

minor atropisomer:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.93 (d, *J* = 9.4 Hz, 1H, *H3* or *H4*), 6.86 (d, *J* = 9.4 Hz, 1H, *H3* or *H4*), 3.95 (s, 3H, CO_2CH_3), 3.92 (s, 3H, CO_2CH_3'), 1.29 (s, 3H, C4'CH_3), 1.28–1.24 (overlapping multiplet, 2H, *H*$_b$*6'* & *H1'*), 1.09 (s, 3H, C4'CH_3'), 0.98 (dd, *J* = 6.6, 4.5 Hz, 1H, *H*$_a$*6'*), 0.49 (s, 3H, SiCH_3), and 0.24 (s, 3H, SiCH_3').

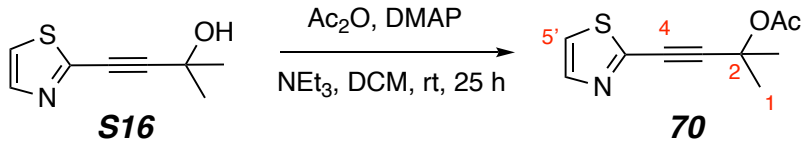
^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 165.76, 159.4, 148.15, 128.5, 127.5, 126.0, 118.15, 115.61, 115.4, 81.4, 52.53, 52.46, 31.9, 30.1, 27.0, 13.7, 12.2, 1.8, and -2.4.

The following data are taken from the mixture of atropisomers:

IR (neat): 2975, 2953, 1729, 1492, 1446, 1208, 1176, and 1104 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{19}H_{24}{}^{35}ClN_2O_5Si^+$, 423.1138; found, 423.1133.

2-Methyl-4-(thiazol-2-yl)but-3-yn-2-yl acetate (70)



S16 ***70***

To a solution of 2-methyl-4-(thiazol-2-yl)but-3-yn-2-ol[28] (**S16**, 90 mg, 0.54 mmol, 1.0 equiv), DMAP (4 mg, 0.032 mmol, 0.06 equiv), NEt_3 (140 µL, 1.0 mmol, 1.9 equiv), and DCM (6 mL) was added Ac_2O (64 µL, 0.68 mmol, 1.3 equiv) at room temperature. The solution was stirred at room temperature for 25 h. Water was added and the crude product was extracted with DCM. The organic layer was washed with brine, passed through a silica plug (EtOAc elution), and concentrated under vacuum to afford **70** (94 mg, 83%) as a clear colorless oil. No further purification was performed.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.80 (d, *J* = 3.3 Hz, 1H, *H4'*), 7.34 (d, *J* = 3.3 Hz, 1H, *H5'*), 2.06 (s, 3H, O=CC*H*$_3$), and 1.77 [s, 6H, C2(C*H*$_3$)$_2$].

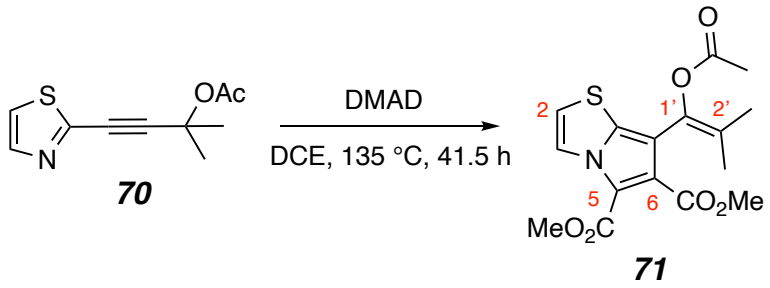
^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 169.4, 148.4, 143.5, 120.9, 94.9, 77.3, 71.8, 28.7, and 21.9.

IR (neat): 3117, 3084, 2989, 2937, 1740, 1479, 1367, 1264, 1236, and 1137 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{10}H_{12}NO_2S^+$, 210.0583; found, 210.0585.

Compound **71**, containing the same pyrrolo[2,1-*b*]thiazole core as cyclopropane **63**, was synthesized in order to further interrogate an unusual, long-range HMBC correlation between *H2* and *C6* that was observed in both pyrrolo[2,1-*b*]thiazole compounds.

Dimethyl 7-(1-Acetoxy-2-methylprop-1-en-1-yl)pyrrolo[2,1-*b*]thiazole-5,6-dicarboxylate (71)



70 ***71***

A solution of **70** (25 mg, 0.12 mmol, 1 equiv), DMAD (51 mg, 0.36 mmol, 3 equiv), and DCE (2 mL) charged with 4 Å molecular sieves was heated in a culture tube at 135 °C for 41.5 h. The crude mixture was passed through a silica plug (EtOAc elution) and concentrated under vacuum. The residue was purified using MPLC (2:1 hex:EtOAc) to afford **71** (28 mg, 67%) as a clear colorless oil.

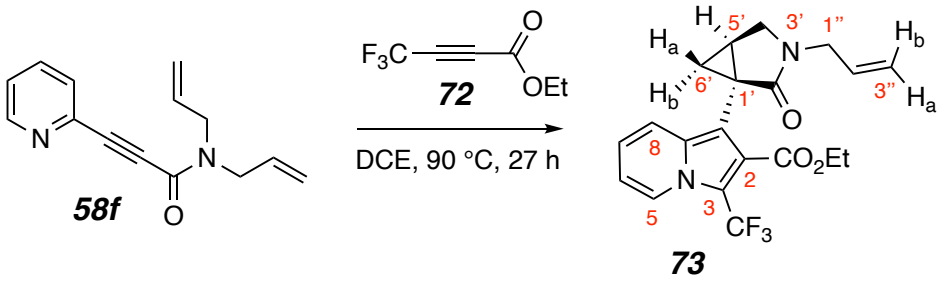
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.32 (d, *J* = 4.3 Hz, 1H, *H3*), 6.97 (d, *J* = 4.2 Hz, 1H, *H2*), 3.91 (s, 3H, C6CO_2CH_3), 3.87 (s, 3H, C5CO_2CH_3'), 2.09 (s, 3H, O=CCH_3), 1.77 (s, 3H, C2'CH_3), and 1.71 (s, 3H, C2'CH_3').

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 169.5 (Me*C*OC1'), 165.8 (C6*C*=O), 160.2 (C5*C*=O), 137.1 (*C*8), 132.9 (*C*1'), 126.8 (*C*6), 125.0 (*C*2'), 122.7 (*C*3), 115.2 (*C*2), 112.7 (*C*5), 109.3 (*C*7), 52.7 (C6CO_2CH_3), 51.8 (C5CO_2CH_3), 20.6 (CH_3COC1'), 19.7 (C2'CH_3), and 18.1 (C2'CH_3').

IR (neat): 3153, 3119, 2992, 2952, 2914, 2859, 1736, 1697, 1487, 1440, 1377, 1226, 1211, and 1122 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{16}H_{18}NO_6S^+$, 352.0849; found, 352.0849.

(±)-Ethyl 1-((1*S*,5*R*)-3-Allyl-2-oxo-3-azabicyclo[3.1.0]hexan-1-yl)-3-(trifluoromethyl)indolizine-2-carboxylate (73)



A solution of **58f** (13 mg, 0.057 mmol, 1 equiv), ethyl 4,4,4-trifluorobut-2-ynoate (**72**, 29 mg, 0.17 mmol, 3 equiv), and DCE (1.5 mL) charged with 4 Å molecular sieves was heated in a culture tube at 90 °C for 27 h. The crude mixture was passed through a silica plug (EtOAc elution) and the eluant was concentrated under vacuum. The residue was purified using MPLC (1:1 hex:EtOAc) to afford **73** (14 mg, 62%) as a white crystalline solid.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.14 (dddd, *J* = 7.3, 0.9, 0.9, 0.9 Hz, 1H, *H5*), 7.70 (ddd, *J* = 9.1, 1.3, 1.3 Hz, 1H, *H8*), 6.96 (ddd, *J* = 9.2, 6.6, 1.1 Hz, 1H, *H7*), 6.77 (ddd, *J* = 7.2, 6.6, 1.4 Hz, 1H, *H6*), 5.74 (dddd, *J* = 17.1, 10.1, 6.0, 6.0 Hz, 1H, *H2"*), 5.23 (dddd, *J* = 17.1, 1.5, 1.5, 1.5 Hz, 1H, *H$_b$3"*), 5.20 (dddd, *J* = 10.1, 1.3, 1.3, 1.3 Hz, 1H, *H$_a$3"*), 4.40 (dq, *J* = 10.7, 7.1 Hz, 1H, $CO_2CH_aH_b$), 4.32 (dq, *J* = 10.8, 7.1 Hz, 1H, $CO_2CH_aH_b$), 3.91 (dddd, *J* = 15.3, 6.0, 1.5, 1.5 Hz, 1H, C1"*H$_a$*H$_b$), 3.82 (dddd, *J* = 15.3, 6.1, 1.4, 1.4 Hz, 1H, C1"H$_a$*H$_b$*), 3.66 (ddd, *J* = 10.0, 5.7, 0.5 Hz, 1H, C4'*H$_a$*H$_b$), 3.34 (d, *J* = 10.2 Hz, 1H, C4'H$_a$*H$_b$*), 2.03 (dddd, *J* = 7.8, 5.8, 4.4, 0.6 Hz, 1H, *H5'*), 1.43 (dd, *J* = 7.8, 4.3 Hz, 1H, *H$_b$6'*), 1.36 (t, *J* = 7.1 Hz, 3H, $CO_2CH_2CH_3$), and 1.22 (dd, *J* = 4.4, 4.4 Hz, 1H, *H$_a$6'*).

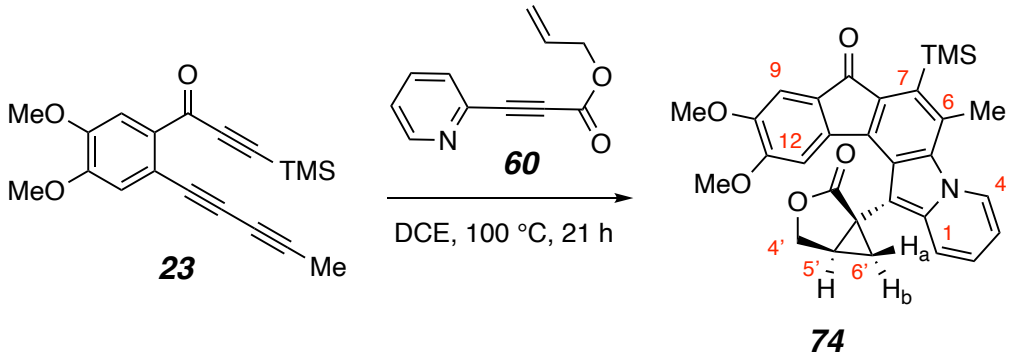
^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 174.0 (N*C*=O), 164.4 (*C*O_2Et), 135.0, 133.1, 124.8 (*C*5, q, J_{CF} = 4.7 Hz), 123.1, 121.6 (q, J_{CF} = 266 Hz), 120.8, 119.0, 117.9, 114.3, 110.0 (q, J_{CF} = 39.2 Hz), 109.2, 61.6, 47.9, 45.4, 26.2, 19.4, 19.3, and 14.2.

IR (neat): 3080, 2985, 2920, 2877, 2855, 1727, 1688, 1532, 1520, 1414, 1264, 1208, 1152, and 1098 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{20}H_{20}F_3N_2O_3^+$, 393.1421; found, 393.1421.

mp: 97–100 °C.

(±)-10,11-Dimethoxy-6-methyl-13-((5*R*)-2-oxo-3-oxabicyclo[3.1.0]hexan-1-yl)-7-(trimethylsilyl)-8*H*-indeno[1,2-*e*]pyrido[1,2-*a*]indol-8-one (74)



In a threaded culture tube, triyne **23** (25 mg, 0.08 mmol) was added to a solution of **60** (29 mg, 0.15 mmol) in DCE (2 mL). The tube was closed with a Teflon®-lined cap, and the solution was heated at 100 °C for 21 h. The solvent was removed and the residue was purified by MPLC (1:1 hex:EtOAc) to afford **74** (14 mg, 36%) as a dark purple amorphous solid.

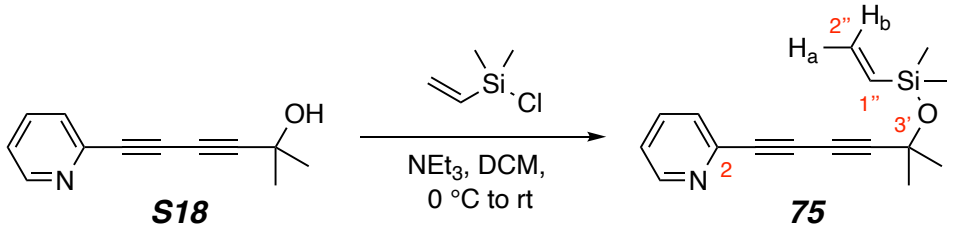
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.74 (ddd, *J* = 7.5, 1.1, 1.0 Hz, 1H, *H4*), 7.65 (s, 1H, *H12*), 7.31 (ddd, *J* = 9.1, 1.3, 1.3 Hz, 1H, *H1*), 7.14 (s, 1H, *H9*), 7.05 (ddd, *J* = 9.2, 6.4, 1.1 Hz, 1H, *H2*), 6.54 (ddd, *J* = 7.6, 6.3, 1.4 Hz, 1H, *H3*), 4.77 (dd, *J* = 9.7, 4.9 Hz, 1H, *H4'*), 4.46 (dd, *J* = 9.8, 0.7 Hz, 1H, *H4'*), 3.92 (s, 3H, C10OC*H*$_3$), 3.91 (s, 3H, C11OC*H*$_3$), 2.94 (s, 3H, C6C*H*$_3$), 2.31 (dddd, *J* = 7.6, 4.9, 4.9, 0.8 Hz, 1H, *H5'*), 1.92 (dd, *J* = 7.8, 5.2 Hz, 1H, *H6'b*), 1.53 (dd, *J* = 5.0, 5.0 Hz, 1H, *H6'a*), and 0.46 [s, 9H, C7Si(C*H*$_3$)$_3$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 195.5, 177.2, 153.6, 148.5, 140.4, 140.2, 136.5, 136.2, 134.3, 132.4, 130.0, 128.9, 126.7, 125.2, 124.6, 117.2, 109.5, 108.5, 107.1, 96.9, 68.4, 56.7, 56.3, 27.4, 26.0, 24.2, 24.0, and 3.2.

IR (neat): 2997, 2942, 2904, 2836, 1762, 1702, 1492, 1358, 1290, and 1214 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{30}H_{30}NO_5Si^+$, 512.1888; found, 512.1873.

2-(5-((Dimethyl(vinyl)silyl)oxy)-5-methylhexa-1,3-diyn-1-yl)pyridine (75)



To a solution of 2-methyl-6-(pyridin-2-yl)hexa-3,5-diyn-2-ol[29] (**S18**, 153 mg, 0.83 mmol, 1.0 equiv) in DCM (5 mL) was added NEt_3 (0.23 mL, 1.65 mmol, 2.0 equiv) and chloro(dimethyl)vinylsilane (0.17 mL, 1.25 mmol, 1.5 equiv) under N_2 at 0 °C. The solution was warmed to room temperature and stirred for 3 h. Water was added and the crude product was extracted with DCM. The organic layer was washed with brine, dried with $MgSO_4$, and concentrated under vacuum. The resulting residue was purified by flash column chromatography (6:1 hex:EtOAc) to afford **75** (183 mg, 82%) as a clear colorless oil.

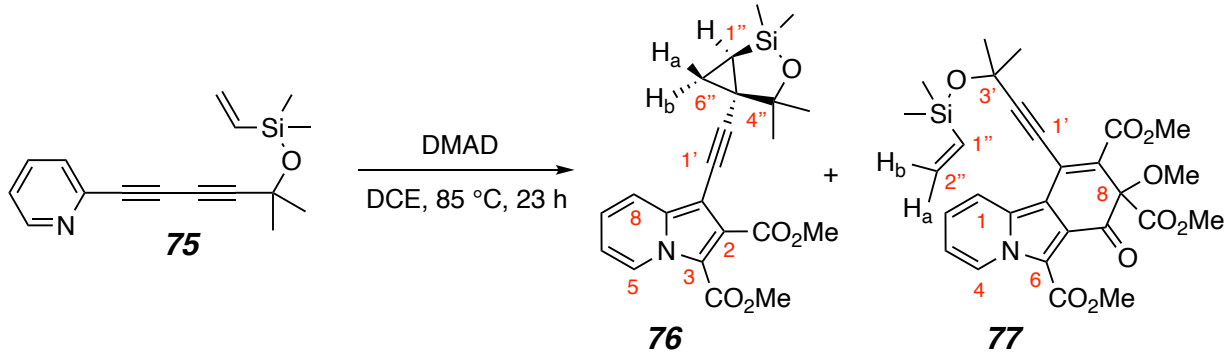
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.59 (ddd, *J* = 4.9, 1.9, 1.0 Hz, 1H, *H6*), 7.66 (ddd, *J* = 7.7, 7.7, 1.8 Hz, 1H, *H4*), 7.49 (ddd, *J* = 7.8, 1.1, 1.1 Hz, 1H, *H3*), 7.26 (ddd, *J* = 7.7, 4.9, 1.2 Hz, 1H, *H5*), 6.26 (dd, *J* = 20.4, 14.8 Hz, 1H, *H1"*), 6.00 (dd, *J* = 14.8, 3.7 Hz, 1H, *H2"$_a$*), 5.79 (dd, *J* = 20.4, 3.7 Hz, 1H, *H2"$_b$*), 1.55 [s, 6H, C3'(CH_3)$_2$], and 0.29 [s, 6H, Si(CH_3)$_2$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 150.4, 142.4, 139.0, 136.3, 132.5, 128.2, 123.6, 88.4, 77.5, 73.3, 68.0, 67.3, 32.7, and 0.1.

IR (neat): 3051, 2984, 2967, 2242, 2156, 1579, 1462, 1428, 1251, 1214, 1157, and 1027 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{16}H_{20}NOSi^+$, 270.1309; found, 270.1307.

(±)-Dimethyl 1-(((1*R*,5*S*)-2,2,4,4-Tetramethyl-3-oxa-2-silabicyclo[3.1.0]hexan-5-yl)ethynyl)indolizine-2,3-dicarboxylate (76)
and
(±)-Trimethyl 10-(3-((Dimethyl(vinyl)silyl)oxy)-3-methylbut-1-yn-1-yl)-8-methoxy-7-oxo-7,8-dihydropyrido[2,1-*a*]isoindole-6,8,9-tricarboxylate (77)



75 *76* *77*

A solution of **75** (30 mg, 0.11 mmol, 1 equiv), DMAD (47 mg, 0.33 mmol, 3 equiv), and DCE (2 mL) was charged with 4 Å molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 85 °C for 23 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (5:1 hex:EtOAc) to afford, in order of elution, **76** (35 mg, 76%) as a clear colorless oil and **77** (2 mg, 3%) as a yellow oil.

A product similar to **77** has been isolated from an analogous reaction described by Xu and Hoye.[29]

Data for 76:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.37 (ddd, *J* = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 7.62 (ddd, *J* = 8.9, 1.3, 1.3 Hz, 1H, *H8*), 7.16 (ddd, *J* = 8.9, 6.7, 1.1 Hz, 1H, *H7*), 7.16 (ddd, *J* = 7.2, 6.7, 1.4 Hz, 1H, *H6*), 3.96 (s, 3H, CO_2CH_3), 3.89 (s, 3H, CO_2CH_3'), 1.58 (s, 3H, C4"CH_3), 1.36 (s, 3H, C4"CH_3'), 1.26 (dd, *J* = 10.5, 4.0 Hz, 1H, *H_b6"*), 0.91 (dd, *J* = 7.2, 4.0 Hz, 1H, *H_a6"*), 0.81 (dd, *J* = 10.5, 7.2 Hz, 1H, *H1"*), 0.35 (s, 3H, SiCH_3), and 0.18 (s, 3H, SiCH_3').

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 165.8, 160.6, 138.1, 129.6, 127.6, 123.8, 118.8, 115.1, 110.7, 97.3, 96.8, 79.6, 69.1, 52.7, 51.9, 30.0, 29.1, 27.1, 16.2, 15.8, 1.4, and -2.6.

IR (neat): 2973, 2958, 2931, 1737, 1691, 1504, 1386, 1244, 1209, and 1097 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H^+]: calcd for $C_{22}H_{26}NO_5Si^+$, 412.1575; found, 412.1577.

Data for 77:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.34 (ddd, *J* = 7.3, 1.2, 1.2 Hz, 1H, *H4*), 8.76 (ddd, *J* = 9.2, 1.3, 1.3 Hz, 1H, *H1*), 7.21 (ddd, *J* = 9.3, 6.7, 1.2 Hz, 1H, *H2*), 7.01 (ddd, *J* = 7.2, 6.7, 1.4 Hz, 1H,

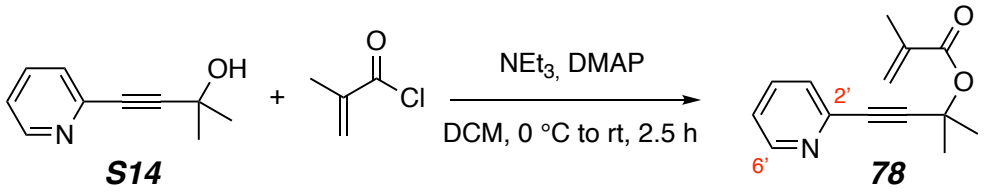
H3), 6.23 (dd, *J* = 20.4, 14.8 Hz, 1H, *H1"*), 5.92 (dd, *J* = 14.8, 3.7 Hz, 1H, *H2"*$_a$), 5.76 (dd, *J* = 20.4, 3.7 Hz, 1H, *H2"*$_b$), 3.97 (s, 3H, CO_2CH_3), 3.84 (s, 3H, CO_2CH_3'), 3.78 (s, 3H, CO_2CH_3''), 3.37 (s, 3H, C8OCH_3), 1.71 (s, 3H, C3'CH_3), 1.69 (s, 3H, C3'CH_3'), and 0.27 [s, 6H, Si(CH_3)$_2$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 187.8, 167.2, 165.6, 161.5, 139.1, 134.2, 132.7, 132.0, 127.8, 124.7, 123.6, 123.4, 120.3, 116.7, 113.5, 112.7, 105.3, 85.9, 78.5, 68.1, 54.3, 53.4, 52.5, 52.3, 32.44, 32.37, 0.4, and 0.1.

IR (neat): 2982, 2952, 2904, 2837, 2222, 1771, 1697, 1505, 1434, 1238, 1211, and 1155 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{28}H_{32}NO_9Si^+$, 554.1841; found, 554.1846.

2-Methyl-4-(pyridin-2-yl)but-3-yn-2-yl Methacrylate (78)



To a solution of 2-methyl-4-(pyridin-2-yl)but-3-yn-2-ol[23] (**S14**, 150 mg, 0.93 mmol, 1 equiv), NEt_3 (0.65 mL, 4.66 mmol, 5 equiv), and DMAP (11 mg, 0.09 mmol, 0.1 equiv) in DCM (3 mL), cooled to 0 °C, was added methacryloyl chloride (0.14 mL, 1.43 mmol, 1.5 equiv). The solution was warmed to room temperature and stirred for 2.5 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The resulting residue was purified by flash column chromatography (2:1 hex:EtOAc) to afford **78** (183 mg, 86%) as a clear slightly yellow oil.

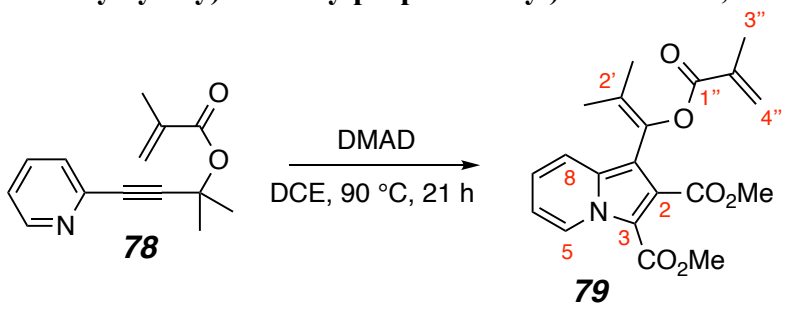
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.56 (ddd, *J* = 4.9, 1.8, 1.0 Hz, 1H, *H6′*), 7.62 (ddd, *J* = 7.7, 7.7, 1.8 Hz, 1H, *H4′*), 7.44 (ddd, *J* = 7.8, 1.1, 1.1 Hz, 1H, *H3′*), 7.21 (ddd, *J* = 7.6, 4.9, 1.2 Hz, 1H, *H5′*), 6.09 (dq, *J* = 1.9, 1.0 Hz, 1H, =CH_ZH$_E$), 5.56 (dq, *J* = 1.7, 1.7 Hz, 1H, =CH$_Z$$H_E$), 1.94 (dd, *J* = 1.7, 1.0 Hz, 1H, =CCH_3), and 1.82 [s, 6H, OC(CH_3)$_2$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 165.7, 150.0, 143.1, 137.1, 136.2, 127.6, 125.5, 123.0, 90.2, 83.5, 72.2, 29.0, and 18.4.

IR (neat): 3053, 2988, 2928, 2857, 1719, 1581, 1462, 1296, 1173, and 1120 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{14}H_{16}NO_2^+$, 230.1176; found, 230.1173.

Dimethyl 1-(1-(Methacryloyloxy)-2-methylprop-1-en-1-yl)indolizine-2,3-dicarboxylate (79)



A solution of **78** (40 mg, 0.17 mmol, 1 equiv), DMAD (74 mg, 0.52 mmol, 3 equiv), and DCE (2 mL) charged with 4 Å molecular sieves was heated in a culture tube at 90 °C for 21 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (3:1 hex:EtOAc) to afford **79** (50 mg, 77%) as a clear colorless oil.

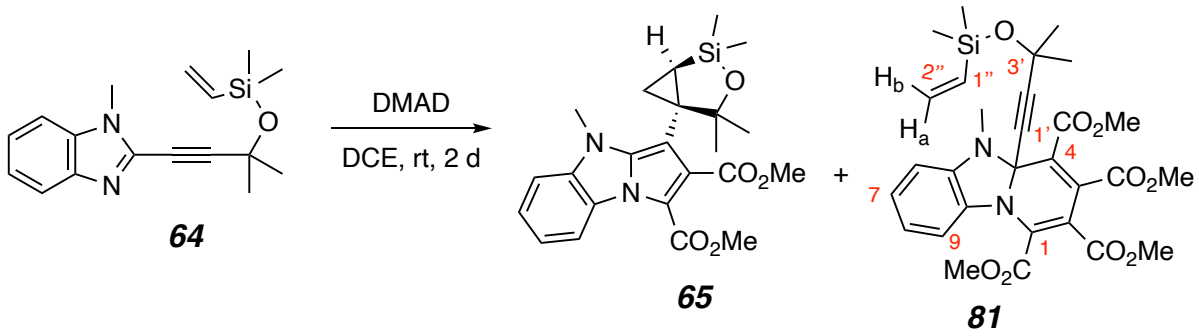
^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.37 (ddd, *J* = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 7.60 (ddd, *J* = 9.0, 1.3, 1.3 Hz, 1H, *H8*), 7.15 (ddd, *J* = 9.0, 6.7, 1.2 Hz, 1H, *H7*), 6.90 (ddd, *J* = 7.1, 6.7, 1.4 Hz, 1H, *H6*), 6.16 (dq, *J* = 1.9, 1.0 Hz, 1H, =CH_ZH$_E$), 5.60 (dq, *J* = 1.6, 1.6 Hz, 1H, =CH$_Z$*H$_E$*), 3.92 (s, 3H, CO_2CH_3), 3.87 (s, 3H, CO_2CH_3'), 1.92 (dd, *J* = 1.7, 1.0 Hz, 3H, C3"C*H$_3$*), 1.80 (s, 3H, C2'C*H$_3$*), and 1.65 (s, 3H, C2'C*H$_3$'*).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 166.6, 165.8, 160.8, 136.0, 135.5, 132.7, 127.39, 127.35, 126.4, 125.9, 123.6, 119.2, 114.5, 110.9, 109.1, 52.6, 51.7, 20.0, 18.4, and 18.1.

IR (neat): 3120, 2990, 2952, 2916, 2856, 1728, 1691, 1501, 1439, 1384, 1210, 1156, 1132, 1116, and 1102 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{14}H_{16}NO_2^+$, 372.1442; found, 372.1469.

(±)-Tetramethyl 4a-(3-((Dimethyl(vinyl)silyl)oxy)-3-methylbut-1-yn-1-yl)-5-methyl-4a,5-dihydrobenzo[4,5]imidazo[1,2-*a*]pyridine-1,2,3,4-tetracarboxylate (81)



A solution of the benzimidazole derivative **64** (30 mg, 0.1 mmol, 1 equiv), DMAD (71 mg, 0.5 mmol, 5 equiv), and DCE (1 mL) was charged with 4 Å molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and held at room temperature for 46.5 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (3:1 hex:EtOAc) to afford, in order of elution, **65** (10 mg, 23%) and **81** (45 mg, 77%) as a red-orange oil.

Data for 81

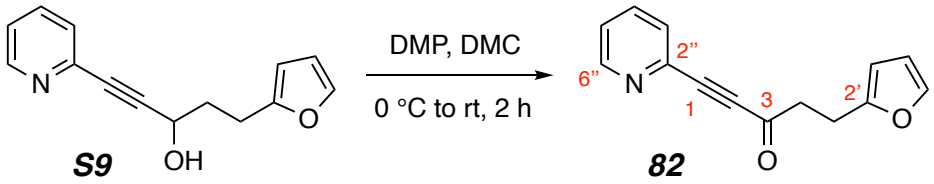
^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.06 (ddd, *J* = 7.5, 7.5, 1.0 Hz, 1H, *H7*), 6.76 (ddd, *J* = 7.6, 7.6, 1.2 Hz, 1H, *H8*), 6.72–6.69 (overlapping m, 2H, *H6* & *H9*), 6.13 (dd, *J* = 20.5, 14.8 Hz, 1H, *H1"*), 5.84 (dd, *J* = 14.9, 3.8 Hz, 1H, *H2"$_a$*), 5.66 (dd, *J* = 20.5, 3.8 Hz, 1H, *H2"$_b$*), 4.04 (s, 3H, CO_2CH_3), 3.81 (s, 3H, CO_2CH_3'), 3.76 (s, 3H, CO_2CH_3''), 3.75 (s, 3H, CO_2CH_3'''), 3.17 (s, 3H, NCH_3), 1.45 (s, 3H, C3'CH_3), 1.41 (s, 3H, C3'CH_3'), 0.16 (s, 3H, $SiCH_3$), and 0.15 (s, 3H, $SiCH_3$').

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 166.8, 163.9, 163.4, 163.3, 143.2 (C5a), 139.0 (C1"), 138.6 (C1 or C3), 132.3 (C2"), 131.8 (C1 or C3), 128.9 (C9a), 125.9 (C7), 120.3 (C8), 115.1 (C2 or C4), 111.1 (C9), 110.5 (C6), 104.8 (C2 or C4), 94.9 (C2'), 79.7 (C4a), 75.3 (C1'), 66.7 (C3'), 53.6, 52.7, 52.4, 52.1, 35.5, 32.9, 32.8, -0.19, and -0.22.

IR (neat): 3050, 2983, 2952, 2901, 2841, 2841, 2825, 2223, 1741, 1708, 1500, 1435, 1354, 1230, 1201, 1161, 1145, and 1034 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{29}H_{35}N_2O_9Si^+$, 583.2106; found, 583.2109.

5-(Furan-2-yl)-1-(pyridin-2-yl)pent-1-yn-3-one (82)



To a solution of **S9** (200 mg, 0.88 mmol, 1 equiv) in DCM (5 mL) cooled to 0 °C, was added DMP (448 mg, 1.1 mmol, 1.2 equiv), and the resulting suspension was stirred for 1 h at 0 °C. The suspension was then allowed to warm to room temperature and stir for an additional 1 h. The reaction mixture was quenched with an aqueous solution of $Na_2S_2O_3$, and the crude product was extracted with DCM. The organic layer was washed with brine, dried with $MgSO_4$, and concentrated under vacuum. The resulting residue was purified by flash column chromatography (2:1 → 1.5:1 hex:EtOAc) to afford **82** (154 mg, 78%) as an orange oil. The concentrated product shows signs of decomposing at room temperature; it was used in the next reaction soon after preparation.

The sample used for the NMR spectra contained remaining amounts of EtOAc solvent because of the limited lifetime of the material following concentration.

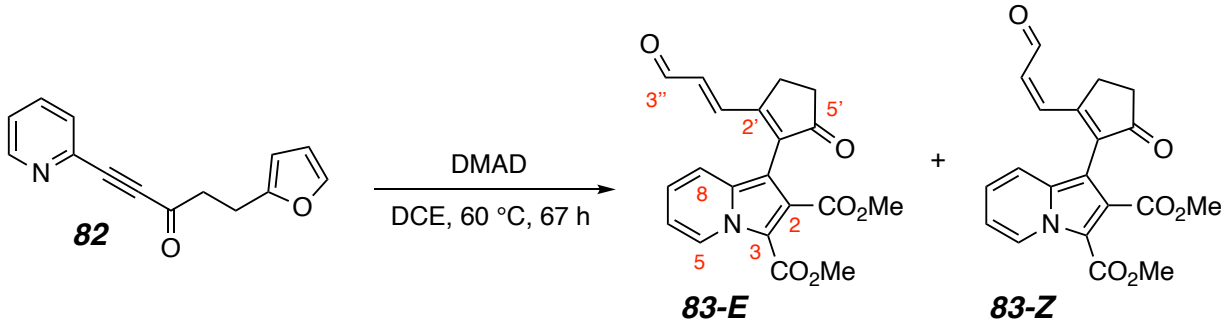
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.68 (ddd, *J* = 4.9, 1.8, 1.0 Hz, 1H, *H6"*), 7.74 (ddd, *J* = 7.8, 7.8, 1.8 Hz, 1H, *H4"*), 7.60 (ddd, *J* = 7.8, 1.1, 1.1 Hz, 1H, *H3"*), 7.37 (ddd, *J* = 7.7, 4.8, 1.2 Hz, 1H, *H5"*), 7.31 (dd, *J* = 1.9, 0.8 Hz, 1H, *H5'*), 6.28 (dd, *J* = 3.2, 1.9 Hz, 1H, *H4'*), 6.05 (ddt, *J* = 3.2, 0.9, 0.9 Hz, 1H, *H3'*), and 3.08–3.07 (m, 4H, *H4, H5*).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 186.1, 153.7, 150.7, 141.5, 140.9, 136.6, 129.0, 124.8, 110.4, 105.7, 88.6, 85.5, 43.8, and 22.4.

IR (neat): 3118, 3055, 2999, 2955, 2915, 2854, 2212, 1672, 1578, 1461, 1429, 1275, and 1012 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{14}H_{12}NO_2^+$, 226.0863; found, 226.0863.

Dimethyl (*E*)-1-(5-Oxo-2-(3-oxoprop-1-en-1-yl)cyclopent-1-en-1-yl)indolizine-2,3-dicarboxylate (83-*E*)
and
Dimethyl (*Z*)-1-(5-Oxo-2-(3-oxoprop-1-en-1-yl)cyclopent-1-en-1-yl)indolizine-2,3-dicarboxylate (83-*Z*)



A solution of **82** (32 mg, 0.14 mmol, 1.0 equiv), DMAD (61 mg, 0.43 mmol, 3.0 equiv), and DCE (2 mL) was charged with 4 Å molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 60 °C for 67 h. The crude mixture was passed through a silica plug (EtOAc elution) and the eluate was concentrated under vacuum. The residue was purified using MPLC (1:2 hex:EtOAc) to afford **83-*Z*** (28 mg, 54%) and **83-*E*** (2 mg, 4%) initially, each an orange amorphous solid. Under ambient light conditions, the cis isomer **83-*Z*** readily photoisomerizes to an equilibrium mixture of **83-*Z*** and the trans isomer **83-*E***. Therefore, **83-*Z*** was handled with minimal light exposure during characterization. The trans isomer **83-*E*** slowly crystallized during storage at in a freezer at ca. –20 °C.

Data for the trans (83-*E*) isomer:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.60 (d, *J* = 7.7 Hz, 1H, *H3"*), 9.45 (ddd, *J* = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 7.48 (dt, *J* = 16.0, 1.0 Hz, 1H, *H1"*), 7.24 (ddd, *J* = 9.0, 1.2, 1.2 Hz, 1H, *H8*), 7.15 (ddd, *J* = 9.0, 6.7, 1.2 Hz, 1H, *H7*), 6.97 (ddd, *J* = 7.2, 6.7, 1.4 Hz, 1H, *H6*), 6.60 (dd, *J* = 15.9, 7.7 Hz, 1H, *H2"*), 3.92 (s, 3H, CO_2CH_3), 3.84 (s, 3H, CO_2CH_3'), 2.97–2.95 (m, 2H, *H4'*), and 2.75–2.72 (m, 2H, *H3'*).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 206.5, 193.4, 166.1, 161.2, 160.9, 144.9, 139.8, 135.2, 133.0, 127.8, 127.7, 124.1, 118.5, 115.0, 113.3, 104.0, 52.8, 52.0, 34.5, and 26.1.

IR (neat): 2997, 2953, 2925, 2853, 1681, 1500, 1439, 1218, and 1092 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{20}H_{18}NO_6^+$, 368.1129; found, 368.1130.

mp: 195–200 °C with decomposition.

Data for the cis (83-*Z*) isomer:

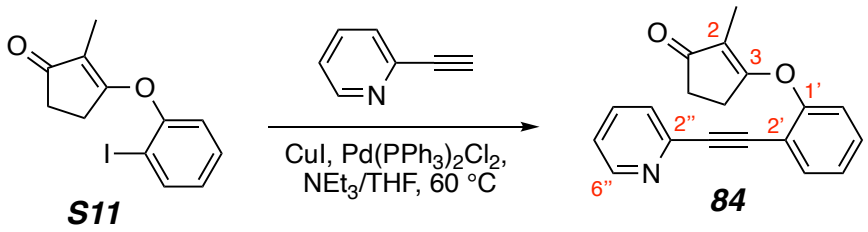
^{1}H-NMR (500 MHz, $CDCl_3$): δ 10.28 (d, *J* = 8.2 Hz, 1H, *H3"*), 9.42 (ddd, *J* = 7.2, 1.0, 1.0 Hz, 1H, *H5*), 7.21–7.11 (m, 3H, *H7, H8, H1"*), 6.95 (ddd, *J* = 7.2, 6.6, 1.4 Hz, 1H, *H6*), 6.08 (dd, *J* = 12.1, 8.1 Hz, 1H, *H2"*), 3.91 (s, 3H, CO_2CH_3), 3.86 (s, 3H, CO_2CH_3'), 3.21–3.08 (broad m, 2H, *H4'*), and 2.77 (t, *J* = 5.1 Hz, 2H, *H3'*).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 206.2, 191.0, 166.0, 161.2, 161.0, 140.2, 140.0, 134.9, 133.4, 127.8, 127.6, 124.0, 118.4, 114.9, 113.4, 104.2, 52.7, 52.0, 35.2, and 31.2.

IR (neat): 2996, 2952, 2849, 1692, 1665, 1498, 1439, 1216, and 1094 cm^{-1}.

HRMS (ESI-TOF) *m/z* [$M+H^+$]: calcd for $C_{20}H_{18}NO_6^+$, 368.1129; found, 368.1130.

2-Methyl-3-(2-(pyridin-2-ylethynyl)phenoxy)cyclopent-2-en-1-one (84)



To a solution of 2-ethynylpyridine (0.17 mL, 1.7 mmol, 1.0 equiv) and **S11** (532 mg, 1.7 mmol, 1.0 equiv) in Et_3N (4 mL) and THF (3 mL) was added $Pd(PPh_3)_2Cl_2$ (24 mg, 0.034 mmol, 0.02 equiv) and CuI (13 mg, 0.068 mmol, 0.04 equiv). The reaction vessel was purged with N_2, and the solution was stirred at 60 °C for 16 h. Upon completion, the crude mixture was passed through a silica plug (EtOAc elution) and concentrated under vacuum. The residue was purified by flash column chromatography (1:1 → 1:2 hex:EtOAc) to afford the sample of **84** (475 mg, 97%) as a green-brown crystalline solid.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.61 (ddd, *J* = 4.9, 1.9, 1.0 Hz, 1H, *H6"*), 7.69–7.65 (m, 2H, *H4'* & *H4"*), 7.43 (ddd, *J* = 8.1, 7.5, 1.7 Hz, 1H, *H5'*), 7.32 (ddd, *J* = 7.8, 1.1, 1.1 Hz, 1H, *H3"*), 7.29 (dd, *J* = 7.6, 1.2 Hz, 1H, *H3'*), 7.26 (dd, *J* = 7.6, 4.9, 1.2 Hz, 1H, *H5"*), 7.20 (dd, *J* = 8.2, 1.2 Hz, 1H, *H6'*), 2.53–2.50 (nfom, 2H, *H4*), 2.47–2.45 (nfom, 2H, *H5*), and 1.72 (t, *J* = 1.8 Hz, 3H, C2C*H*$_3$).

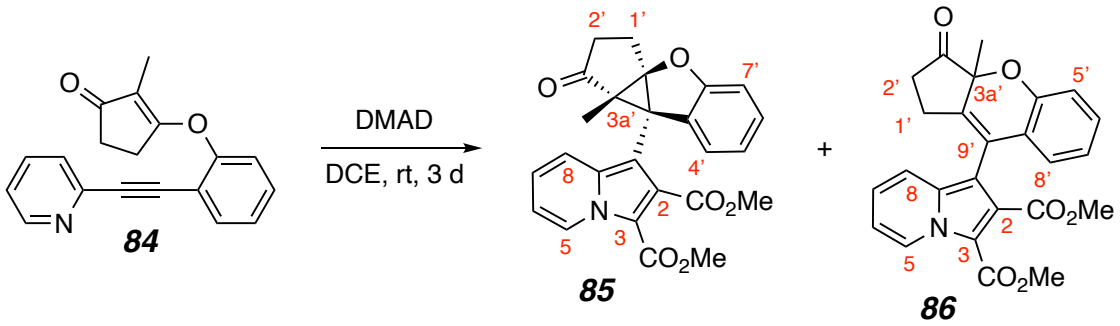
^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 206.0, 182.0, 155.1, 150.4, 142.8, 136.5, 133.9, 130.6, 127.2, 126.2, 123.4, 121.7, 118.8, 116.5, 94.3, 83.3, 34.0, 26.0, and 6.4.

IR (neat): 3056, 2975, 2922, 2863, 2223, 1697, 1639, 1579, 1486, 1378, 1327, 1222, and 1106 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{19}H_{16}NO_2^+$, 290.1176; found, 290.1194.

mp: 71–74 °C.

(±)-Dimethyl 1-((3b*S*,8a*S*)-3a-Methyl-3-oxo-1,2,3,3a-tetrahydro-3b*H*-cyclopenta[1,3]cyclopropa[1,2-*b*]benzofuran-3b-yl)indolizine-2,3-dicarboxylate (85)
and
(±)-Dimethyl 1-(3a-Methyl-3-oxo-1,2,3,3a-tetrahydrocyclopenta[*b*]chromen-9-yl)indolizine-2,3-dicarboxylate (86)



A solution of **84** (40 mg, 0.14 mmol, 1.0 equiv), DMAD (59 mg, 0.42 mmol, 3.0 equiv), and DCE (2 mL) was charged with 4 Å molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and allowed to stand at room temperature for 3 d. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (3:1 hex:EtOAc) to afford **85** and **86**, each as a pair of separable atropisomers. Each of **85-maj** (24 mg, 40%) and **85-min** (18 mg, 30%) was isolated as a white crystalline solid. Each of **86-maj** (6 mg, 10%) and **86-min** (4 mg, 7%) was isolated as a clear-colorless oil. The order of elution was: **85-maj**, **85-min**, **86-maj**, and then **86-min**.

When each separate atropisomer **85-maj** or **85-min** was independently heated at 80 °C for 47 h in $CDCl_3$, each atropisomer converted to a mixture of the (same ratio of the) rearranged isomeric (atropisomers of) **86-maj** and **86-min**. Then, when each separate atropisomer **86-maj** or **86-min** was independently heated at 80 °C for 6 d in $CDCl_3$, each atropisomer converted to an equilibrium mixture of 1.4:1 (**86-maj**:**86-min**).

Data for the major atropisomer 85-maj:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.37 (ddd, *J* = 7.2, 1.2, 1.2 Hz, 1H, *H5*), 7.54 (ddd, *J* = 9.0, 1.3, 1.3 Hz, 1H, *H8*), 7.20 (ddd, *J* = 8.2, 7.2, 1.5 Hz, 1H, *H6'*), 7.15 (ddd, *J* = 9.0, 6.8, 1.1 Hz, 1H, *H7*), 6.97 (ddd, *J* = 8.2, 0.8, 0.8 Hz, 1H, *H7'*), 6.92 (ddd, *J* = 7.2, 6.8, 1.3 Hz, 1H, *H6*), 6.89 (ddd, *J* = 7.4, 7.4, 1.0 Hz, 1H, *H5'*), 6.84 (ddd, *J* = 7.6, 1.5, 0.5 Hz, 1H, *H4'*), 3.85 (s, 3H, C3CO_2CH_3), 3.52 (s, 3H, C2CO_2CH_3), 2.88 (ddd, *J* = 12.9, 8.7, 1.2 Hz, 1H, C1'H_aH_b), 2.73 (ddd, *J* = 12.9, 10.3, 9.2 Hz 1H, C1'H_aH_b), 2.20 (ddd, *J* = 18.6, 10.3, 1.2 Hz 1H, C2'H_aH_b), 1.49 (ddd, *J* = 18.6, 8.9, 8.9 Hz 1H, C2'H_aH_b), and 1.03 (s, 3H, C3a'CH_3).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 213.3, 166.1, 160.8, 158.7, 135.2, 130.7, 128.4, 128.1, 127.4, 125.1, 123.7, 121.8, 118.3, 114.9, 111.9, 109.6, 108.5, 86.3, 52.3, 51.8, 41.5, 36.4, 35.5, 23.8, and 7.6.

IR (neat): 3123, 3032, 2991, 2951, 2929, 2887, 1723, 1694, 1504, 1439, 1395, 1367, 1217, and 1189 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{25}H_{22}NO_6^+$, 432.1442; found, 432.1480.

mp: 161–165 °C.

Data for the minor atropisomer 85-min:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.37 (ddd, *J* = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 7.22–7.19 (m, 2H, *H7* or *H8 & H4'*), 7.17 (ddd, *J* = 8.9, 1.3, 1.3 Hz, 1H, *H7'*), 7.00–6.96 (m, 2H, *H7* or *H8 & H6'*), 6.91 (ddd, *J* = 7.5, 7.5, 1.0 Hz, 1H, *H5'*), 6.86 (ddd, *J* = 7.1, 6.8, 1.4 Hz, 1H, *H6*), 3.95 (s, 3H, CO_2CH_3), 3.90 (s, 3H, CO_2CH_3'), 2.75 (ddd, *J* = 12.9, 10.1, 9.3 Hz, 1H, C1'H_aH$_b$), 2.62 (ddd, *J* = 12.9, 8.8, 1.1 Hz, 1H, C1'H$_a$$H_b$), 2.20 (ddd, *J* = 18.2, 10.1, 1.2 Hz, 1H, C2'H_aH$_b$), 1.41 (ddd, *J* = 18.1, 9.2, 8.7 Hz, 1H, C2'H$_a$$H_b$), and 0.86 (s, 3H, C3a'CH_3).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 211.1, 166.1, 161.0, 158.6, 135.9, 130.5, 128.4, 127.7, 127.4, 126.3, 123.3, 122.1, 117.7, 114.8, 111.3, 109.7, 109.1, 85.5, 52.8, 51.8, 41.0, 36.9, 35.6, 24.7, and 7.0.

IR (neat): 3122, 3011, 2951, 2883, 1725, 1693, 1504, 1459, 1439, 1391, 1222, and 1188 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{25}H_{22}NO_6^+$, 432.1442; found, 432.1482.

mp: 182–184 °C.

Data for the major atropisomer 86-maj:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.47 (ddd, *J* = 7.1, 1.2, 1.2 Hz, 1H, *H5*), 7.54 (ddd, *J* = 8.2, 7.4, 1.7 Hz, 1H, *H6'*), 7.07 (dd, *J* = 8.1, 1.3 Hz, 1H, *H5'*), 7.00–6.99 (m, 2H, *H7* & *H8*), 6.93 (nfom, 1H, *H6*), 6.79 (ddd, *J* = 7.5, 7.5, 1.3 Hz, 1H, *H7'*), 6.68 (dd, *J* = 7.7, 1.7 Hz, 1H, *H8'*), 3.94 (s, 3H, CO_2CH_3), 3.85 (s, 3H, CO_2CH_3'), 2.72 (ddd, *J* = 16.3, 10.5, 8.1 Hz, 1H, C1'H_aH$_b$), 2.41 (ddd, *J* = 18.6, 10.5, 2.0 Hz, 1H, C2'H_aH$_b$), 2.50 (ddd, *J* = 15.3, 10.4, 2.0 Hz, 1H, C1'H$_a$$H_b$), 2.41 (ddd, *J* = 18.0, 10.2, 8.2 Hz, 1H, C2'H$_a$$H_b$), and 1.46 (s, 3H, C3a'CH_3).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 212.0, 166.7, 160.9, 150.5, 138.2, 134.5, 129.5, 129.2, 127.6, 125.9, 123.3, 122.8, 122.1, 121.8, 118.8, 117.5, 114.8, 111.4, 108.1, 81.0, 52.7, 51.9, 35.1, 22.9, and 19.9.

IR (neat): 3120, 3071, 3026, 2952, 2923, 2853, 1760, 1735, 1690, 1501, 1439, 1383, 1212, and 1052 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{25}H_{22}NO_6^+$, 432.1442; found, 432.1484.

Data for the minor atropisomer 86-min:

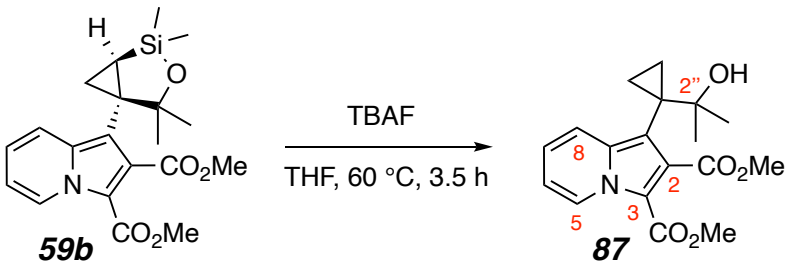
^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.49 (ddd, *J* = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 7.32 (ddd, *J* = 8.9, 1.3, 1.3 Hz, 1H, *H8*), 7.18–7.13 (m, 2H, *H7* & *H6'*), 7.03 (dd, *J* = 8.1, 1.2 Hz, 1H, *H5'*), 6.97 (ddd, *J* = 7.1, 6.7, 1.4 Hz, 1H, *H6*), 6.82 (ddd, *J* = 7.7, 7.7, 1.2 Hz, 1H, *H7'*), 6.79 (dd, *J* = 7.7, 2.0 Hz, 1H, *H8'*), 3.90 (s, 3H, C3CO_2C*H*$_3$), 3.47 (s, 3H, C2CO_2C*H*$_3$), 2.69–2.59 (nfom, 1H, C2'*H*$_a$H$_b$), 2.54–2.46 (m, 3H, C2'H$_a$*H*$_b$, and C1'*H*$_2$), and 1.53 (s, 3H, C3a'C*H*$_3$).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 212.0, 165.8, 161.0, 150.6, 136.7, 135.3, 129.5, 127.9, 126.9, 126.0, 123.4, 122.8, 122.0, 121.7, 118.0, 117.3, 114.6, 111.9, 108.6, 80.6, 52.3, 51.9, 35.3, 23.2, and 20.2.

IR (neat): 3121, 3069, 3031, 2952, 2921, 2855, 1761, 1734, 1693, 1500, 1439, 1386, 1258, 1217, and 1054 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{25}H_{22}NO_6^+$, 432.1442; found, 432.1483.

Dimethyl 1-(1-(2-Hydroxypropan-2-yl)cyclopropyl)indolizine-2,3-dicarboxylate (87)



To a culture tube charged with **59b** (50 mg, 0.13 mmol, 1 equiv) in THF (1 mL) at room temperature was added TBAF (0.32 mL, 0.32 mmol, 2.5 equiv; 1 M in THF) dropwise. The mixture was heated at 60 °C for 3.5 h. Sat. $NaHCO_3$ was added and the mixture was extracted with EtOAc. The organic layer was washed with brine, dried with $MgSO_4$, and concentrated under vacuum. The resulting residue was purified by flash column chromatography (2:1 hex:EtOAc) to afford **87** (40 mg, 94%) as a white crystalline solid.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.39 (ddd, *J* = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 7.73 (ddd, *J* = 9.0, 1.3, 1.3 Hz, 1H, *H8*), 7.09 (ddd, *J* = 9.1, 6.7, 1.2 Hz, 1H, *H7*), 6.87 (ddd, *J* = 7.2, 6.7, 1.4 Hz, 1H, *H6*), 3.95 (s, 3H, CO_2CH_3), 3.87 (s, 3H, CO_2CH_3), 3.20 (s, 3H, C2''O*H*), 1.22 (s, 3H, C2''CH_3), 1.14 (s, 3H, C2''CH_3'), 1.13–1.02 (nfom, 2H, CH_2), and 0.77–0.71 (nfom, 2H, CH_2).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 168.7, 160.9, 136.6, 128.8, 127.4, 122.4, 119.3, 116.4, 114.3, 110.5, 72.7, 52.9, 51.7, 28.8, 27.1, 25.0, 10.7, and 10.0.

IR (neat): 3600–3400, 3090, 2976, 2951, 1735, 1686, 1495, 1383, 1211, 1181, and 1121 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{18}H_{22}NO_5^+$, 332.1492; found, 332.1491.

mp: 166–167 °C.

(±)-Dimethyl 1-((1*R*,2*R*)-2-Hydroxy-1-(2-hydroxypropan-2-yl)cyclopropyl)indolizine-2,3-dicarboxylate (88)

To a culture tube charged with **59b** (50 mg, 0.13 mmol, 1.0 equiv) in DMF (2 mL) at room temperature was added KF (31 mg, 0.53 mmol, 4.1 equiv), $KHCO_3$ (52 mg, 0.52 mmol, 4.0 equiv), and 30% H_2O_2 solution (0.11 mL, 1.08 mmol, 8.3 equiv). The mixture was heated at 60 °C and stirred for 30 min. Sat. $Na_2S_2O_3$ was added and the crude product was extracted with EtOAc. The organic layer was washed with brine, dried with $MgSO_4$, and concentrated under vacuum. The resulting residue was purified by flash column chromatography (1:l hex:EtOAc) to afford **88** (44 mg, 98%) as a white crystalline solid.

The ^{1}H NMR spectrum for this material indicated that the compound exists as a 1.3:1 ratio of slowly interconverting (on the NMR time scale) atropisomers.

major atropisomer:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.39–9.36 (overlapping m, 1H, *H5*), 7.60 (ddd, *J* = 9.0, 1.3, 1.3 Hz, 1H, *H8*), 7.09 (ddd, *J* = 9.0, 6.7, 1.2 Hz, 1H, *H7*), 6.88 (overlapping ddd, *J* = 7.2, 6.7, 1.4 Hz, 1H, *H6*), 4.06–4.02 (overlapping m, 1H, *H2''*), 3.97 (s, 3H, CO_2CH_3), 3.89 (s, 3H, CO_2CH_3'), 3.84 (broad s, 1H, C2''O*H*), 3.74 (broad s, 1H, C2'O*H*), 1.80 (dd, *J* = 5.8, 4.1 Hz, 1H, *Ha3''*), 1.36 (s, 3H, C2'CH_3), 1.27 (s, 3H, C2'CH_3'), and 0.90 (dd, *J* = 7.3, 5.8 Hz, 1H, *Hb3''*).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 168.2, 160.9, 136.3, 128.3, 127.6, 122.7, 118.8, 114.3, 114.20, 110.63, 74.3, 59.0, 52.5, 51.8, 29.5, 29.3, 28.6, and 16.6.

minor atropisomer:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.39–9.36 (overlapping m, 1H, *H5*), 7.87 (ddd, *J* = 9.0, 1.3, 1.3 Hz, 1H, *H8*), 7.13 (ddd, *J* = 9.0, 6.7, 1.2 Hz, 1H, *H7*), 6.88 (overlapping ddd, *J* = 7.2, 6.7, 1.4 Hz, 1H, *H6*), 4.04 (br s, 1H, C2''O*H*), 3.91 (s, 3H, CO_2CH_3), 3.86 (s, 3H, CO_2CH_3'), 3.73–3.69 (br m, 1H, *H2''*), 3.31 (broad s, 1H, C2'O*H*), 1.59 (dd, *J* = 6.3, 4.1 Hz, 1H, *Ha3''*), 1.39 (s, 3H, C2'CH_3), 1.35 (s, 3H, C2'CH_3'), and 1.23 (dd, *J* = 7.1, 6.3 Hz, 1H, *Hb3''*).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 167.6, 160.8, 136.5, 129.3, 127.5, 122.9, 119.2, 114.8, 114.19, 110.62, 74.7, 59.1, 52.7, 51.7, 29.8, 29.6, 28.7, and 16.5.

The following data are taken from the mixture of atropisomers:

IR (neat): 3600–3200, 2975, 2951, 1735, 1692, 1496, 1441, 1383, 1220, and 1119 cm^{-1}.

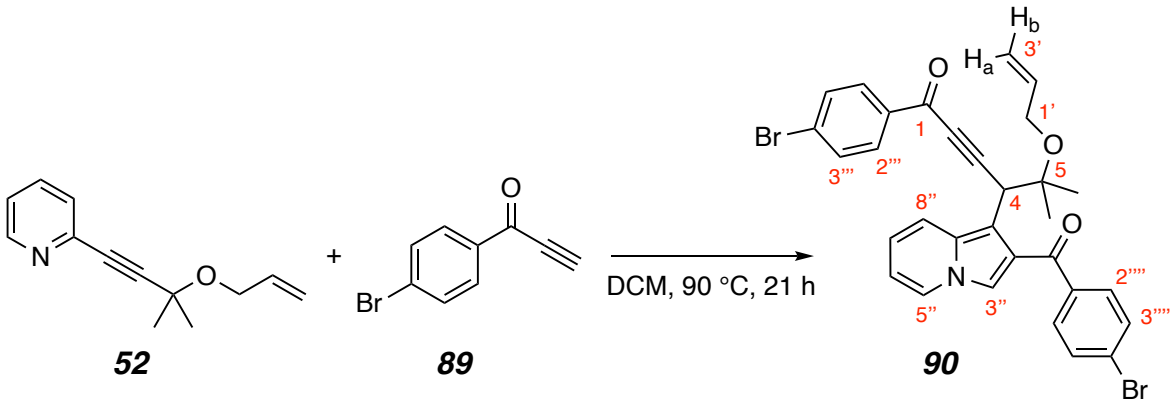
HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{18}H_{22}NO_6^+$, 348.1442; found, 348.1440.

mp: 198–200 °C with decomposition before melting.

Supplementary Information for Chapter IV

I. Experimental Procedures and Characterization Data for New Compounds

(±)-5-(Allyloxy)-4-(2-(4-bromobenzoyl)indolizin-1-yl)-1-(4-bromophenyl)-5-methylhex-2-yn-1-one (90)



52 ***89*** ***90***

A solution of **52** (30 mg, 0.15 mmol, 1.0 equiv), 1-(4-bromophenyl)prop-2-yn-1-one[30] (93 mg, 0.44 mmol, 3.0 equiv), and DCM (2 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 90 °C for 21 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (7:1 hex:EtOAc) to afford **90** (31 mg, 34%) as an orange oil.

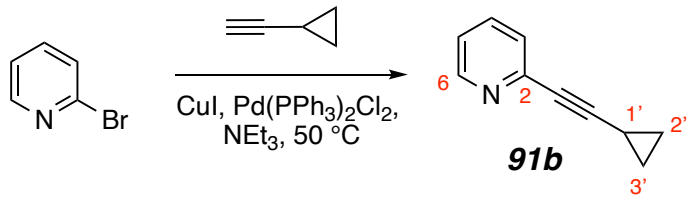
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.08 (nfod, J_{app} = 8.7 Hz, 2H, *H2'''*), 7.98 (dddd, *J* = 9.4, 1.1, 1.1, 1.1 Hz, 1H, *H8''*), 7.79 (ddd, *J* = 7.1, 1.1, 1.1 Hz, 1H, *H5''*), 7.71 (nfod, J_{app} = 8.6 Hz, 2H, *H2''''*), 7.63 (nfod, J_{app} = 8.6 Hz, 2H, *H3''''*), 7.59 (nfod, J_{app} = 8.7 Hz, 2H, *H3'''*), 7.44 (d, *J* = 0.7 Hz, 1H, *H3''*), 6.70 (ddd, *J* = 9.4, 6.5, 1.1 Hz, 1H, *H7''*), 6.57 (ddd, *J* = 7.0, 6.4, 1.2 Hz, 1H, *H6''*), 5.91 (dddd, *J* = 17.2, 10.6, 5.4, 5.4 Hz, 1H, *H2'*), 5.61 (s, 1H, *H4*), 5.28 (dddd, *J* = 17.2, 1.7, 1.7, 1.7 Hz, 1H, H_a*3'*), 5.10 (dddd, *J* = 10.4, 1.4, 1.4, 1.4 Hz, 1H, H_b*3'*), 4.08 (dddd, *J* = 12.2, 5.5, 1.5, 1.5 Hz, 1H, *H1'*), 3.97 (dddd, *J* = 12.2, 5.2, 1.6, 1.6 Hz, 1H, *H1'*), 1.45 (s, 3H, C5CH_3), and 1.27 (s, 3H, C5CH_3').

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 192.6, 177.2, 139.1, 136.2, 136.1, 132.7, 132.0, 131.7, 131.3, 131.1, 129.3, 127.0, 125.5, 124.2, 122.2, 118.8, 118.7, 115.9, 113.2, 109.1, 97.9, 81.4, 79.1, 63.6, 38.8, 23.8, and 23.6.

IR (neat): 3119, 3080, 2978, 2915, 2861, 2220, 2199, 1639, 1583, 1260, 1221, 1172, and 1067 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{31}H_{26}Br_2NO_3^+$, 618.0274; found, 618.0276.

2-(Cyclopropylethynyl)pyridine (91b)



To a solution of 2-bromopyridine (0.3 mL, 3.15 mmol, 1 equiv) and cyclopropylacetylene (0.27 mL, 3.19 mmol, 1 equiv) in Et_3N (6 mL) was added $Pd(PPh_3)_2Cl_2$ (21 mg, 0.03 mmol, 0.01 equiv) and CuI (11 mg, 0.06 mmol, 0.02 equiv). The reaction vessel was purged with N_2, and the suspension was stirred at 50 °C for 24 h. Upon completion, the crude mixture was passed through a silica plug (EtOAc elution) and concentrated under vacuum. The residue was purified by MPLC (5:1 hex:EtOAc) to afford **91b** (103 mg, 23%) as a brown amorphous solid.

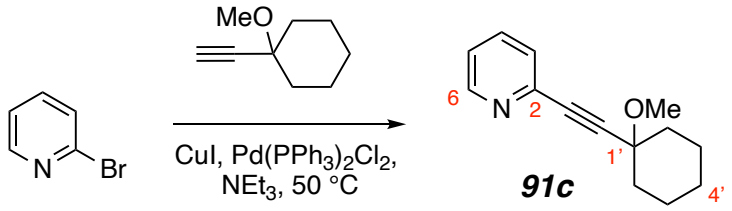
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.52 (ddd, *J* = 4.9, 1.9, 1.0 Hz, 1H, *H6*), 7.59 (ddd, *J* = 7.7, 7.7, 1.8 Hz, 1H, *H4*), 7.34 (ddd, *J* = 7.9, 1.1, 1.1 Hz, 1H, *H3*), 7.16 (ddd, *J* = 7.6, 4.9, 1.2 Hz, 1H, *H5*), 1.48 (nfom), and 0.91–0.87 (m, 4H, *H2'* & *H3'*).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 149.9, 144.0, 136.1, 126.8, 122.2, 94.3, 75.7, 8.8, and 0.2.

IR (neat): 3078, 3050, 3009, 2234, 2219, 1579, 1560, 1463, and 1426 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{10}H_{10}N^+$, 144.0808; found, 144.0807.

2-((1-Methoxycyclohexyl)ethynyl)pyridine (91c)



To a solution of 2-bromopyridine (0.18 mL, 1.9 mmol, 1 equiv) and 1-ethynyl-1-methoxycyclohexane (350 mg, 2.5 mmol, 1.3 equiv) in Et_3N (6.5 mL) was added $Pd(PPh_3)_2Cl_2$ (18 mg, 0.026 mmol, 0.013 equiv) and CuI (10 mg, 0.05 mmol, 0.028 equiv). The reaction vessel was purged with N_2, and the suspension was stirred at 50 °C for 18 h. Upon completion, the crude mixture was passed through a silica plug (EtOAc elution) and concentrated under vacuum. The residue was purified by MPLC (3:1 hex:EtOAc) to afford **91c** (273 mg, 65%) as a yellow oil.

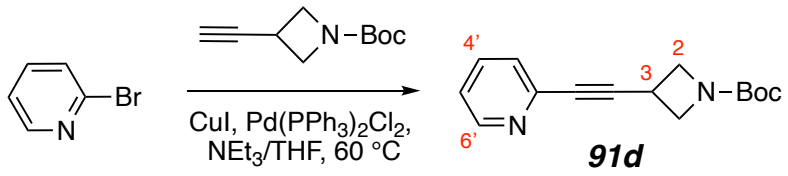
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.59 (ddd, *J* = 4.9, 1.8, 1.0 Hz, 1H, *H6*), 7.64 (ddd, *J* = 7.8, 7.8, 1.8 Hz, 1H, *H4*), 7.44 (ddd, *J* = 7.8, 1.1, 1.1 Hz, 1H, *H3*), 7.22 (ddd, *J* = 7.6, 4.9, 1.2 Hz, 1H, *H5*), 3.46 (s, 3H, OCH_3), 2.06–2.01 (m, 2H, C2'/C6'H_{eq}), 1.74–1.50 (m, 7H, C2'/C6'H_{ax}, C3'/C5'CH_2, and C4'H_aH_b), and 1.38–1.30 (nfom, 1H, C4'H_aH_b).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 150.1, 143.3, 136.2, 127.4, 122.9, 90.7, 85.6, 74.3, 51.2, 36.7, 25.5, and 22.9.

IR (neat): 3077, 3051, 2933, 2857, 1581, 1461, 1427, and 1088 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{14}H_{18}NO^+$, 216.1383; found, 216.1383.

***tert*-Butyl 3-(Pyridin-2-ylethynyl)azetidine-1-carboxylate (91d)**



To a solution of 2-bromopyridine (0.146 mL, 1.53 mmol, 1 equiv) and *tert*-butyl 3-ethynylazetidine-1-carboxylate (306 mg, 1.69 mmol, 1.1 equiv) in Et_3N (3 mL) and THF (3 mL) was added $Pd(PPh_3)_2Cl_2$ (22 mg, 0.031 mmol, 0.02 equiv) and CuI (12 mg, 0.063 mmol, 0.04 equiv). The reaction vessel was purged with N_2, and the suspension was stirred at 60 °C for 3 h. The crude mixture was passed through a silica plug (EtOAc elution) and concentrated under vacuum. The residue was purified by flash column chromatography (4:1 → 2:1 hex:EtOAc) to afford **91d** (265 mg, 67%) as an orange oil.

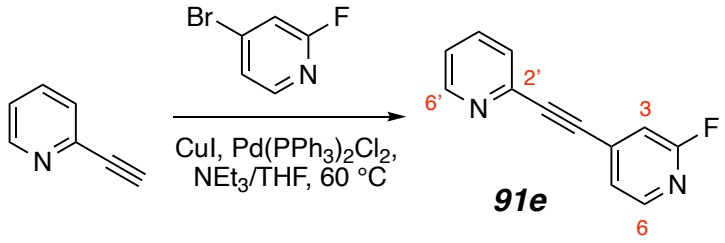
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.57 (ddd, *J* = 4.9, 1.8, 1.0 Hz, 1H, *H6'*), 7.65 (ddd, *J* = 7.7, 7.7, 1.9 Hz, 1H, *H4'*), 7.40 (ddd, *J* = 7.9, 1.2, 1.2 Hz, 1H, *H3'*), 7.23 (ddd, *J* = 7.7, 4.9, 1.2 Hz, 1H, *H5'*), 4.21 (dd, *J* = 8.6, 8.6 Hz, 2H, C2H_aH$_b$), 4.08 (dd, *J* = 8.4, 6.4 Hz, 2H, C2H$_a$$H_b$), 3.57 (tt, *J* = 8.8, 6.4 Hz, 1H, *H3*), and 1.45 [s, 9H, C(CH_3)$_3$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 156.1, 150.1, 143.2, 136.3, 127.0, 123.0, 89.6, 83.2, 79.9, 55.4 (br), 28.5, and 19.8.

IR (neat): 3052, 2973, 2933, 2889, 2236, 1698, 1582, 1464, 1392, 1366, and 1133 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{15}H_{19}N_2O_2^+$, 259.1441; found, 259.1436.

2-Fluoro-4-(pyridin-2-ylethynyl)pyridine (91e)



To a solution of 2-ethynylpyridine (0.29 mL, 2.9 mmol, 1 equiv) and 4-bromo-2-fluoropyridine (0.3 mL, 2.9 mmol, 1 equiv) in Et_3N (8 mL) and THF (6 mL) was added $Pd(PPh_3)_2Cl_2$ (41 mg, 0.058 mmol, 0.02 equiv) and CuI (22 mg, 0.12 mmol, 0.03 equiv). The reaction vessel was purged with N_2, and the suspension was stirred at 60 °C for 4 d. The crude mixture was passed through a silica plug (EtOAc elution) and concentrated under vacuum. The residue was purified by flash column chromatography (2:1 → 1.5:1 hex:EtOAc) to afford **91e** (228 mg, 40%) as a yellow crystalline solid.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.67 (ddd, *J* = 4.9, 1.8, 1.0 Hz, 1H, *H6'*), 8.24 (ddd, *J* = 5.1, 0.8, 0.8 Hz, 1H, *H6*), 7.74 (ddd, *J* = 7.8, 7.8, 1.8 Hz, 1H, *H4'*), 7.58 (ddd, *J* = 7.8, 1.1, 1.1 Hz, 1H, *H3'*), 7.34 (ddd, *J* = 5.0, 3.0, 1.2 Hz, 1H, *H5*), 7.33 (ddd, *J* = 7.6, 4.8, 1.2 Hz, 1H, *H5'*), and 7.10 (ddd, *J* = 2.1, 1.2, 0.8 Hz, 1H, *H3*).

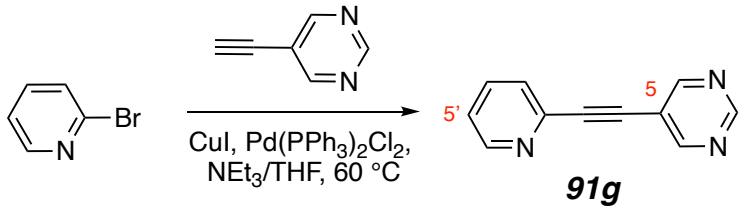
^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 163.8 (d, *J* = 238.8 Hz, *C2*), 150.5 (*C6'*), 148.0 (d, *J* = 15.7 Hz, *C6*), 142.1 (*C2'*), 136.5 (*C4'*), 135.5 (d, *J* = 9.4 Hz, *C4*), 127.8 (*C3'*), 124.0 (C5'), 123.8 (d, *J* = 4.5 Hz, *C5*), 112.0 (d, *J* = 39.3 Hz, *C3*), 93.7 (pyC_{sp}), and 84.8 (d, *J* = 5.0 Hz), (FpyC_{sp}).
HSQC
HMBC

IR (neat): 3145, 3051, 3007, 2222, 1600, 1543, 1479, 1401, 1249, 1215, and 1130 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{12}H_8FN_2^+$, 199.0666; found, 199.0665.

mp: 58–61 °C.

5-(Pyridin-2-ylethynyl)pyrimidine (91g)



91g

To a solution of 2-bromopyridine (0.25 mL, 2.6 mmol, 1 equiv) and 5-ethynylpyrimidine (300 mg, 2.9 mmol, 1.1 equiv) in Et_3N (3 mL) and THF (3 mL) was added $Pd(PPh_3)_2Cl_2$ (37 mg, 0.05 mmol, 0.02 equiv) and CuI (20 mg, 0.10 mmol, 0.04 equiv). The reaction vessel was purged with N_2, and the suspension was stirred at 60 °C for 3 h. The crude mixture was passed through a silica plug (EtOAc elution) and concentrated under vacuum. The residue was purified by crystallization in which hexanes was added dropwise to a solution of the crude reaction mixture dissolved in EtOAc. The crystallization afforded **91g** (361 mg, 76%) as a light brown crystalline solid.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.19 (s, 1H, *H2*), 8.93 (s, 2H, *H4*), 8.67 (ddd, *J* = 4.9, 1.8, 1.0 Hz, 1H, *H6'*), 7.75 (ddd, *J* = 7.8, 7.8, 1.8 Hz, 1H, *H4'*), 7.58 (ddd, *J* = 7.8, 1.1, 1.1 Hz, 1H, *H3'*), and 7.33 (ddd, *J* = 7.7, 4.9, 1.2 Hz, 1H, *H5'*).

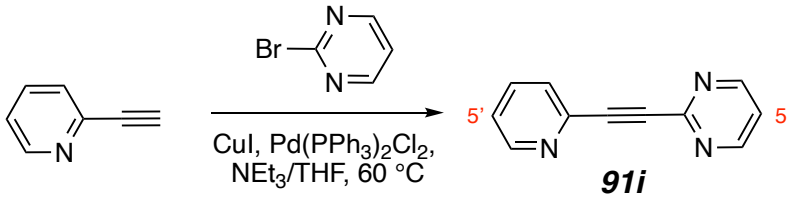
^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 159.2, 157.4, 150.5, 142.3, 136.6, 127.6, 123.9, 119.2, 95.2, and 81.9.

IR (neat): 3088, 3053, 3030, 2915, 1583, 1567, 1545, 1462, 1428, and 1412 cm^{-1}.

HRMS (ESI-TOF) *m/z* [$M+H^+$]: calcd for $C_{11}H_8N_3^+$, 182.0713; found, 182.0709.

mp: 92–96 °C.

2-(Pyridin-2-ylethynyl)pyrimidine (91i)



To a solution of 2-bromopyrimidine (394 mg, 2.5 mmol, 1 equiv) and 2-ethynylpyridine (0.3 mL, 3.0 mmol, 1.2 equiv) in Et_3N (3 mL) and THF (3 mL) was added $Pd(PPh_3)_2Cl_2$ (35 mg, 0.05 mmol, 0.02 equiv) and CuI (19 mg, 0.10 mmol, 0.04 equiv). The reaction vessel was purged with N_2, and the suspension was stirred at 60 °C for 5.5 h. The crude mixture was passed through a silica plug (EtOAc elution) and concentrated under vacuum. The residue was purified by crystallization in which hexanes was added dropwise to a solution of the crude reaction mixture dissolved in EtOAc. The crystallization afforded **91i** (144 mg, 32%) as a brown crystalline solid.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.78 (d, *J* = 4.9 Hz, 2H, *H4*), 8.67 (ddd, *J* = 4.9, 1.8, 1.0 Hz, 1H, *H6'*), 7.72 (ddd, *J* = 7.7, 7.7, 1.8 Hz, 1H, *H4'*), 7.66 (ddd, *J* = 7.8, 1.2, 1.2 Hz, 1H, *H3'*), 7.32 (ddd, *J* = 7.6, 4.8, 1.3 Hz, 1H, *H5'*), and 7.29 (t, *J* = 4.9 Hz, 1H, *H4*).

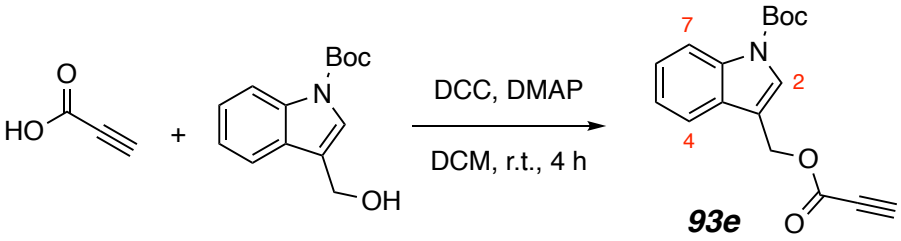
^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 157.4, 153.0, 150.5, 142.1, 136.3, 128.2, 123.9, 120.3, 86.8, and 86.1.

IR (neat): 3121, 3076, 3048, 3029, 2233, 1581, 1553, 1463, 1428, and 1406 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{11}H_8N_3^+$, 182.0713; found, 182.0709.

mp: 122–126 °C.

***tert*-Butyl 3-((Propioloyloxy)methyl)-1*H*-indole-1-carboxylate (93e)**



To a solution of DCC (455 mg, 2.2 mmol, 1 equiv) and DMAP (5 mg, 0.4 mmol, 0.02 equiv) in DCM (4 mL) was added dropwise an ice-cold solution of propiolic acid (0.136 mL, 2.2 mmol, 1 equiv) and *tert*-butyl 3-(hydroxymethyl)-1*H*-indole-1-carboxylate (600 mg, 2.4 mmol, 1.1 equiv) in DCM (4 mL). The solution was stirred at room temperature for 4 h. Water was added, and the crude product was extracted with EtOAc. The organic layer was washed with brine, dried with $MgSO_4$, and concentrated under vacuum. The residue was purified by flash column chromatography (8:1 → 6:1 hex:EtOAc) to afford **93e** (343 mg, 47%) as a white crystalline solid.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.16 (br d, J = 8.1 Hz, 1H, *H7*), 7.69 (s, 1H, *H2*), 7.62 (ddd, J = 7.9, 0.9, 0.9 Hz, 1H, *H4*), 7.36 (ddd, J = 8.5, 7.2, 1.4 Hz, 1H, *H6*), 7.29 (ddd, J = 7.9, 7.4, 1.1 Hz, 1H, *H5*), 5.39 (d, J = 1.0 Hz, 2H, OCH_2), 2.87 (s, 1H, C≡C*H*), and 1.67 [s, 9H, C(CH_3)$_3$].

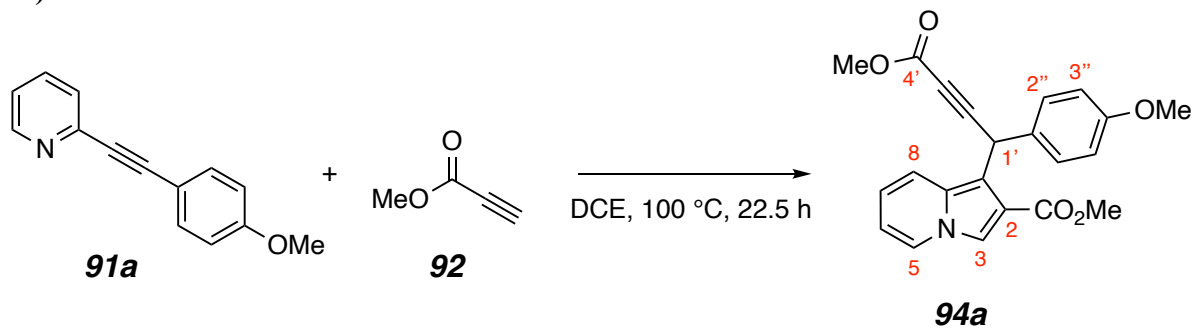
^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 152.8, 149.5, 135.7, 129.2, 126.6, 125.0, 123.1, 119.3, 115.5, 114.4, 84.3, 75.2, 74.6, 59.7, and 28.3.

IR (neat): 3267, 3127, 3055, 2980, 2935, 2119, 1715, 1452, 1385, 1351, 1258, 1212, 1155, and 1091 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+Na$^+$]: calcd for $C_{17}H_{18}NNaO_4^+$, 322.1050; found, 322.1060.

mp: 93–95 °C.

(±)-Methyl 1-(4-Methoxy-1-(4-methoxyphenyl)-4-oxobut-2-yn-1-yl)indolizine-2-carboxylate (94a)



A solution of 2-((4-methoxyphenyl)ethynyl)pyridine[31] (30 mg, 0.14 mmol, 1.0 equiv), methyl propiolate (36 mg, 0.43 mmol, 3.0 equiv), and DCE (2 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 100 °C for 22.5 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (3:1 hex:EtOAc) to afford **94a** (27 mg, 50%) as a yellow–green oil.

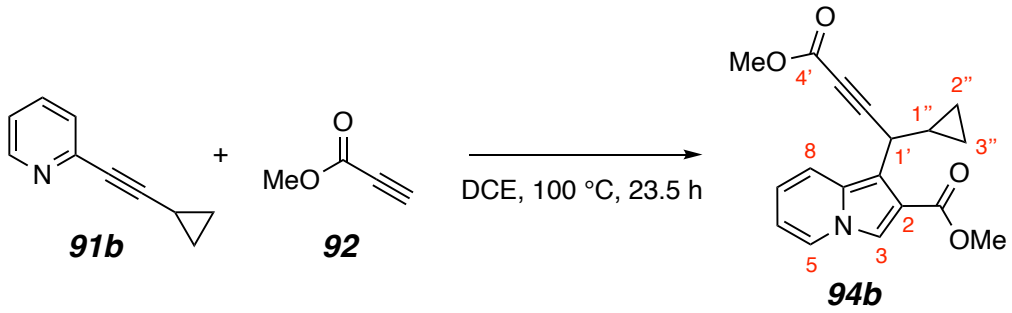
^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.80 (ddd, *J* = 7.1, 1.2, 1.2 Hz, 1H, *H5*), 7.76 (d, *J* = 0.8 Hz, 1H, *H3*), 7.51 (dddd, *J* = 9.3, 1.1, 1.1, 1.1 Hz, 1H, *H8*), 7.37 (nfod, J_{app} = 8.9 Hz, 2H, *H2"*), 6.81 (nfod, J_{app} = 9.0 Hz, 2H, *H3"*), 6.66 (ddd, *J* = 9.3, 6.5, 1.1 Hz, 1H, *H7*), 6.53 (ddd, *J* = 7.1, 6.5, 1.2 Hz, 1H, *H6*), 6.47 (t, *J* = 0.9 Hz, 1H, *H1'*), 3.87 (s, 3H, C2CO_2CH_3), 3.76 (s, 3H, C4'OCH_3), and 3.75 (s, 3H, ArOCH_3).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 165.6, 158.6, 154.5, 131.8, 130.9, 128.4, 125.6, 119.6, 118.5, 116.4, 114.0, 112.9, 111.6, 89.5, 75.2, 55.4, 52.7, 51.5, 31.5. (one carbon resonance not observed)

IR (neat): 3132, 2998, 2952, 2906, 2836, 2232, 1710, 1509, 1437, 1251, and 1207 cm^{-1}.

HRMS (ESI-TOF) *m/z* [$M+H^+$]: calcd for $C_{22}H_{20}NO_5^+$, 378.1336; found, 378.1334.

(±)-Methyl 1-(1-Cyclopropyl-4-methoxy-4-oxobut-2-yn-1-yl)indolizine-2-carboxylate (94b)



91b *92* ***94b***

A solution of **91b** (25 mg, 0.17 mmol, 1.0 equiv), methyl propiolate (44 mg, 0.52 mmol, 3.0 equiv), and DCE (2 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 100 °C for 23.5 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (3:1 hex:EtOAc) to afford **94b** (28 mg, 52%) as a yellow oil.

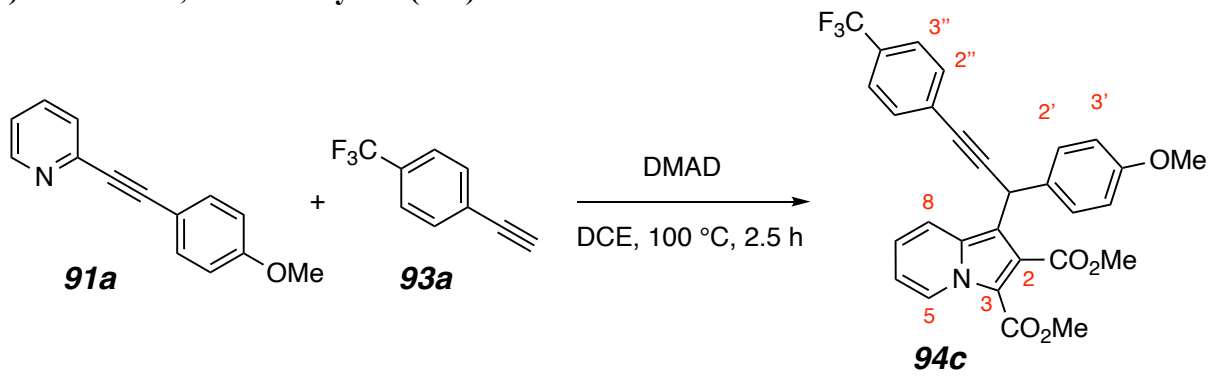
^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.82 (ddd, *J* = 7.1, 1.2, 1.2 Hz, 1H, *H5*), 7.75 (ddd, *J* = 9.2, 2.0, 1.2 Hz, 1H, *H8*), 7.74 (s, 1H, *H3*), 6.72 (ddd, *J* = 9.3, 6.5, 1.1 Hz, 1H, *H7*), 6.55 (ddd, *J* = 7.1, 6.5, 1.2 Hz, 1H, *H6*), 4.70 (d, *J* = 7.7 Hz, 1H, *H1'*), 3.86 (s, 3H, $C2CO_2CH_3$), 3.75 (s, 3H, $C4'OCH_3$), 1.39 (ddddd, *J* = 7.9, 7.9, 7.9, 4.9, 4.9 Hz, 1H, *H1"*), 0.61 (dddd, *J* = 9.3, 8.0, 5.9, 4.6 Hz, 1H, C2"$H_{cis\text{-}to\text{-}R}H_{trans\text{-}to\text{-}R}$), 0.51 (dddd, *J* = 9.4, 6.0, 4.8, 4.8 Hz, 1H, C2"$H_{cis\text{-}to\text{-}R}H_{trans\text{-}to\text{-}R}$), 0.45 (dddd, *J* = 9.2, 5.6, 4.6, 4.6 Hz, 1H, C3"$H_{cis\text{-}to\text{-}R}H_{trans\text{-}to\text{-}R}$), and 0.41 (dddd, *J* = 9.3, 8.1, 6.0, 4.6 Hz, 1H, C3"$H_{cis\text{-}to\text{-}R}H_{trans\text{-}to\text{-}R}$).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 165.6 (CO_2Me), 154.5 (C4'), 130.8 (C9), 125.6 (C5), 119.8 (C8), 118.2 (C7), 116.21 (C3 or C2), 116.20 (C3 or C2), 112.8 (C6), 111.5 (C1), 90.4 (C2'), 73.5 (C3'), 52.7 ($C3'CO_2CH_3$), 51.4 ($C2CO_2CH_3$), 30.9 (C1'), 17.1 (C1"), 4.6 (C2"), and 4.0 (C3").

IR (neat): 3136, 3082, 3003, 2952, 2914, 2230, 1702, 1434, 1247, 1206, and 1096 cm^{-1}.

HRMS (ESI-TOF) *m/z* [$M+H^+$]: calcd for $C_{18}H_{18}NO_4^+$, 312.1230; found, 312.1230.

(±)-Dimethyl 1-(1-(4-Methoxyphenyl)-3-(4-(trifluoromethyl)phenyl)prop-2-yn-1-yl)indolizine-2,3-dicarboxylate (94c)



A solution of 2-((4-methoxyphenyl)ethynyl)pyridine[31] (15 mg, 0.072 mmol, 1 equiv), DMAD (20 mg, 0.014 mmol, 2 equiv), 4-(trifluoromethyl)phenylacetylene (61 mg, 0.36 mmol, 5 equiv), and DCE (1 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 100 °C for 2.5 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (3:1 hex:EtOAc) to afford **91a** (16 mg, 43%) as a yellow oil.

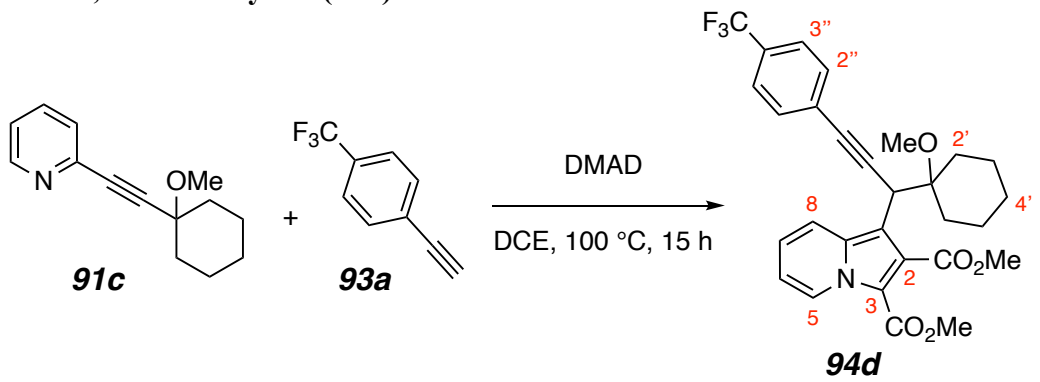
^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.41 (ddd, *J* = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 7.61 (ddd, *J* = 9.0, 1.3, 1.3 Hz, 1H, *H8*), 7.57–7.53 (m, 4H, *H2"*), 7.45 (nfod, J_{app} = 9.0 Hz, 2H, *H2'*), 7.02 (ddd, *J* = 9.1, 6.7, 1.1 Hz, 1H, *H7*), 6.89–6.83 (m, 3H, *H6* & *H3'*), 5.57 (t, *J* = 0.9 Hz, 1H, C≡C-C*H*), 3.89 (s, 6H, C2CO_2CH_3 & C3CO_2CH_3), and 3.77 (s, 3H, ArOCH_3).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 166.9, 160.9, 158.7, 134.2, 132.1, 131.9, 130.0 (q, *J* = 32.7 Hz), 128.6, 127.6, 127.2 (q, *J* = 1.4 Hz), 126.5, 125.3 (q, *J* = 3.8 Hz), 124.1 (q, *J* = 273 Hz), 122.8, 118.4, 114.5, 114.0, 113.2, 110.4, 91.7, 83.2, 55.4, 52.8, 51.7, and 33.4.

IR (neat): 3016, 2998, 2952, 2837, 2343, 1734, 1692, 1509, 1382, 1323, 1213, 1176, and 1126 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{29}H_{23}F_3NO_5^+$, 522.1523; found, 522.1521.

(±)-Dimethyl 1-(1-(1-Methoxycyclohexyl)-3-(4-(trifluoromethyl)phenyl)prop-2-yn-1-yl)indolizine-2,3-dicarboxylate (94d)



A solution of **91c** (30 mg, 0.14 mmol, 1 equiv), DMAD (41 mg, 0.29 mmol, 2 equiv), 1-ethynyl-4-(trifluoromethyl)benzene (119 mg, 0.70 mmol, 5 equiv), and DCE (2 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 100 °C for 15 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (3:1 hex:EtOAc) to afford **94d** (27 mg, 42%) as a yellow oil.

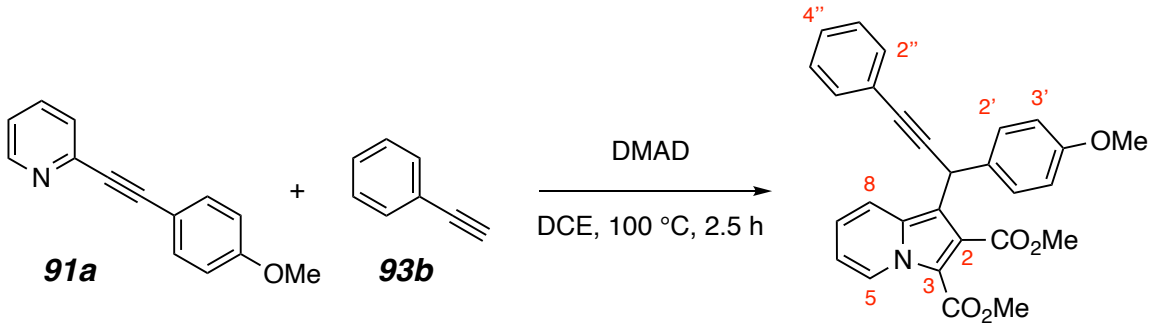
^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.42 (ddd, *J* = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 8.05 (ddd, *J* = 9.2, 1.3, 1.3 Hz, 1H, *H8*), 7.55–7.50 (m, 4H, *H2"* & *H3"*), 7.09 (ddd, *J* = 9.2, 6.6, 1.2 Hz, 1H, *H7*), 6.89 (ddd, *J* = 7.3, 6.7, 1.3 Hz, 1H, *H6*), 4.62 (s, 1H, C≡C-C*H*), 3.93 (s, 3H, CO_2CH_3), 3.89 (s, 3H, CO_2CH_3'), 3.34 (s, 3H, C1'OCH_3), 2.09–2.01 (nfom, 1H, C2'H_{eq} or C6'H_{eq}), 1.89–1.82 (nfom, 1H, C2'H_{eq} or C6'H_{eq}), 1.65–1.37 (m, 7H, C2'/C6'H_{ax}, C3'/C5'CH_2, and C4'H_aH_b), and 1.12–1.01 (nfom, 1H, C4'H_aH_b).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 167.2, 160.9, 135.5, 132.0, 129.7 (q, *J* = 32.6 Hz), 127.6 (*J* = 1.5 Hz), 127.51, 127.45, 125.3 (q, *J* = 3.7 Hz), 124.1 (q, *J* = 272 Hz), 122.4, 120.3, 114.3, 111.0, 109.7, 91.7, 82.6, 79.3, 52.6, 51.8, 49.4, 37.1, 33.0, 30.7, 25.4, 22.10, and 22.07.

IR (neat): 3049, 2943, 2858, 2227, 1728, 1692, 1322, 1214, and 1067 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H^+]: calcd for $C_{29}H_{29}F_3NO_5^+$, 528.1992; found, 528.1994.

(±)-Dimethyl 1-(1-(4-Methoxyphenyl)-3-phenylprop-2-yn-1-yl)indolizine-2,3-dicarboxylate (94e)



A solution of 2-((4-methoxyphenyl)ethynyl)pyridine[31] (30 mg, 0.14 mmol, 1 equiv), DMAD (41 mg, 0.29 mmol, 2 equiv), phenylacetylene (0.5 mL, excess), and DCE (0.5 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 100 °C for 2.5 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (3:1 hex:EtOAc) to afford **94e** (37 mg, 57%) as a yellow oil.

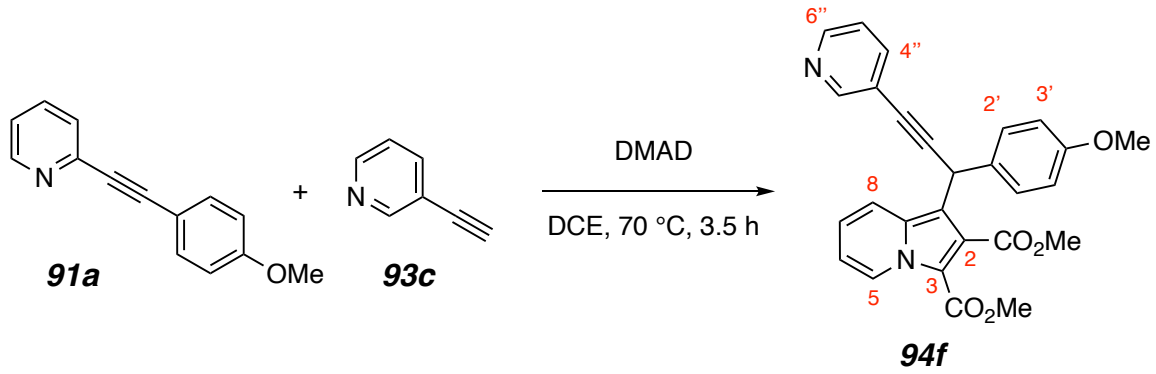
^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.40 (ddd, *J* = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 7.67 (ddd, *J* = 9.1, 1.3, 1.3 Hz, 1H, *H8*), 7.48 (nfod, J_{app} = 9.0 Hz, 2H, *H2'*), 7.47–7.44 (m, 2H, *H2"*), 7.31–7.27 (m, 3H, *H3" & H4")*, 7.01 (ddd, *J* = 9.1, 6.7, 1.2 Hz, 1H, *H7*), 6.87–6.82 (m, 3H, *H6* & *H3'*), 5.54 (t, *J* = 0.9 Hz, 1H, C≡C-C*H*), 3.90 (s, 3H, COOCH_3), 3.89 (s, 3H, COOCH_3'), and 3.76 (s, 3H, C4'OCH_3).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 167.0, 161.0, 158.6, 134.3, 132.4, 131.8, 128.6, 128.4, 128.2, 127.6, 126.5, 123.4, 122.6, 118.6, 114.5, 113.9, 113.8, 110.3, 88.9, 84.5, 55.4, 52.7, 51.7, and 33.3.

IR (neat): 3117, 3059, 2998, 2950, 2902, 2835, 2255, 1731, 1687, 1507, 1379, 1203, and 1091 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{28}H_{24}NO_5^+$, 454.1649; found, 454.1650.

(±)-Dimethyl 1-(1-(4-Methoxyphenyl)-3-(pyridin-3-yl)prop-2-yn-1-yl)indolizine-2,3-dicarboxylate (94f)



A solution of 2-((4-methoxyphenyl)ethynyl)pyridine[31] (30 mg, 0.14 mmol, 1 equiv), DMAD (41 mg, 0.29 mmol, 2 equiv), 3-ethynylpyridine (74 mg, 0.72 mmol, 5 equiv), and DCE (2 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 70 °C for 3.5 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (1:1.7 hex:EtOAc) to afford **94f** (27 mg, 41%) as a yellow oil.

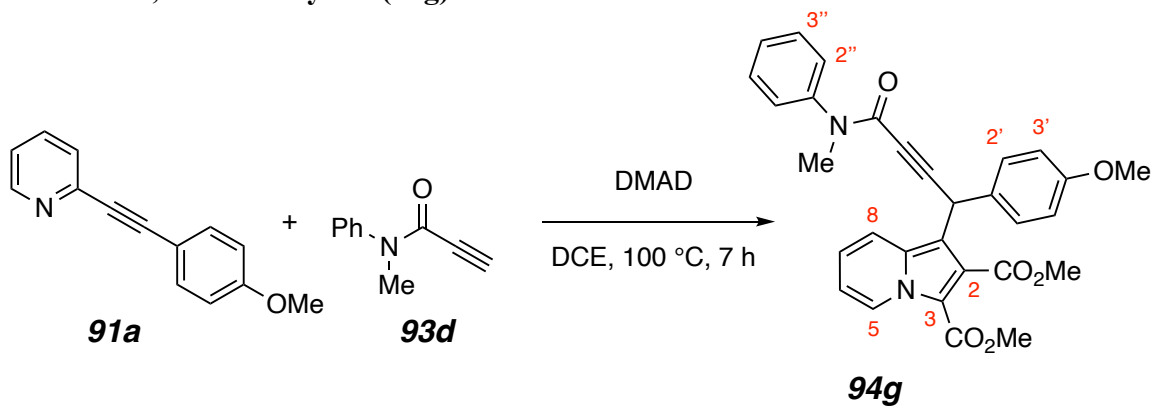
^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.41 (ddd, *J* = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 8.69 (br s, 1H, *H2"*), 8.51 (br d, *J* = 4.4 Hz, 1H, *H6"*), 7.73 (ddd, *J* = 7.9, 1.9, 1.9 Hz, 1H, *H4"*), 7.62 (ddd, *J* = 9.0, 1.2, 1.2 Hz, 1H, *H8*), 7.46 (nfod, J_{app} = 8.9 Hz, 2H, *H2'*), 7.23 (ddd, *J* = 7.9, 4.9, 0.6 Hz, 1H, *H5"*), 7.03 (ddd, *J* = 9.1, 6.7, 1.2 Hz, 1H, *H7*), 6.89–6.84 (m, 3H, *H6* & *H3'*), 5.58 (t, *J* = 0.9 Hz, C≡C-C*H*), 3.90 (s, 3H, COOCH_3), 3.89 (s, 3H, COOCH_3'), and 3.77 (s, 3H, C4'OCH_3).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 166.9, 160.9, 158.7, 152.5, 148.6, 138.8, 134.2, 131.8, 128.5, 127.6, 126.5, 123.12, 122.8, 120.6, 118.4, 114.5, 114.0, 113.1, 110.4, 92.5, 81.2, 55.4, 52.8, 51.7, and 33.4.

IR (neat): 3119, 3030, 2999, 2951, 2904, 2836, 2229, 1732, 1689, 1508, 1381, 1246, 1211, and 1179 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{27}H_{23}N_2O_5^+$, 455.1601; found, 455.1604.

(±)-Dimethyl 1-(1-(4-Methoxyphenyl)-4-(methyl(phenyl)amino)-4-oxobut-2-yn-1-yl)indolizine-2,3-dicarboxylate (94g)



A solution of 2-((4-methoxyphenyl)ethynyl)pyridine[31] (30 mg, 0.14 mmol, 1 equiv), DMAD (41 mg, 0.29 mmol, 2 equiv), *N*-methyl-*N*-phenylpropiolamide[32] (114 mg, 0.72 mmol, 5 equiv), and DCE (2 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 100 °C for 7 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (1.5:1 hex:EtOAc) to afford **94g** (41 mg, 84%) as a yellow oil.

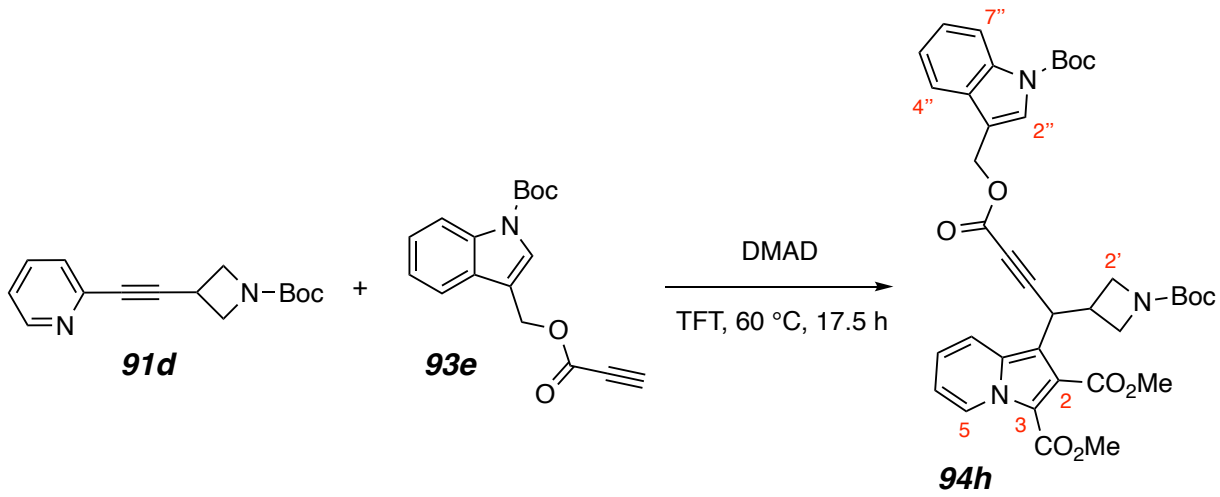
^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.34 (ddd, *J* = 7.1, 1.2, 1.2 Hz, 1H, *H5*), 7.30–7.23 (m, 5H, Ph*H*s), 7.00–6.96 (m, 3H, *H8* & *H2'*), 6.88–6.81 (m, 2H, *H6* & *H7*), 6.68 (nfod, J_{app} = 8.9 Hz, 2H, *H3'*), 5.28 (t, *J* = 0.9 Hz, 1H, C≡C-C*H*), 3.89 (s, 3H, COOCH_3), 3.88 (s, 3H, COOCH_3'), 3.74 (s, 3H, C4'OCH_3), and 3.31 (s, 3H, N-CH_3).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 166.5, 160.9, 158.6, 154.0, 143.2, 133.9, 130.3, 129.2, 128.3, 127.8, 127.6, 127.4, 126.3, 122.5, 118.5, 114.4, 113.8, 112.0, 110.2, 91.3, 78.4, 55.4, 52.7, 51.7, 36.6, and 32.6.

IR (neat): 3117, 3062, 2998, 2951, 2904, 2837, 2224, 1730, 1688, 1632, 1508, 1495, 1376, 1209, 1087, and 1032 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{30}H_{27}N_2O_6^+$, 511.1864; found, 511.1865.

(±)-Dimethyl 1-(4-((1-(*tert*-Butoxycarbonyl)-1*H*-indol-3-yl)methoxy)-1-(1-(*tert*-butoxycarbonyl)azetidin-3-yl)-4-oxobut-2-yn-1-yl)indolizine-2,3-dicarboxylate (94h)



A solution of the azetidine-containing alkynyl pyridine **91d** (25 mg, 0.096 mmol, 1 equiv), the indole derivative **93e** (58 mg, 0.19 mmol, 2 equiv), DMAD (41 mg, 0.29 mmol, 3 equiv), and TFT (1.5 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 60 °C for 17.5 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (2:1 hex:EtOAc) to afford **94h** (41 mg, 61%) as a clear colorless oil.

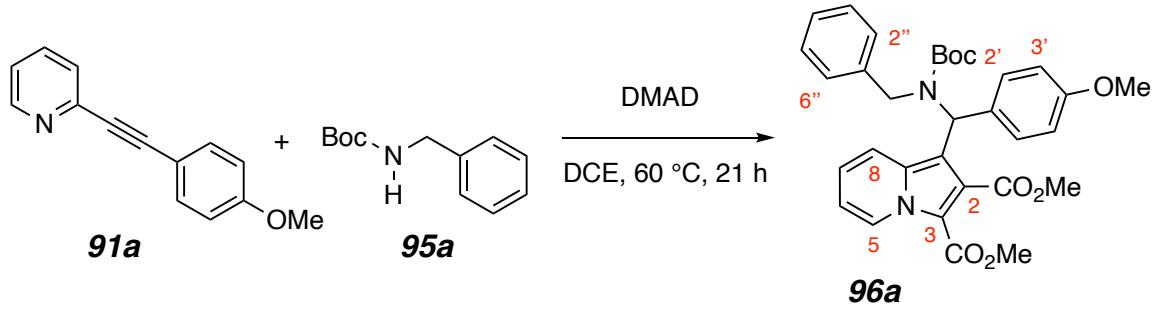
^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.37 (ddd, *J* = 7.3, 1.1, 1.1 Hz, 1H, *H5*), 8.15 (br d, *J* = 8.3 Hz, 1H, *H7"*), 7.68 (br d, *J* = 9.1 Hz, 1H, *H8*), 7.66 (s, 1H, *H2"*), 7.60 (ddd, *J* = 7.8, 1.0, 1.0 Hz, 1H, *H4"*), 7.35 (ddd, *J* = 8.4, 7.2, 1.3 Hz, 1H, *H6"*), 7.27 (ddd, *J* = 8.1, 7.3, 1.1 Hz, 1H, *H5"*), 7.09 (ddd, *J* = 9.1, 6.7, 1.3 Hz, 1H, *H7*), 6.90 (ddd, *J* = 7.3, 6.7, 1.3 Hz, 1H, *H6*), 5.33 (d, *J* = 0.9 Hz, 2H, OCH_2), 4.24 (d, *J* = 10.4 Hz, 1H, C≡C-C*H*), 4.08 (dd, *J* = 9.2, 8.0 Hz, 1H, C2'H_aH_b or C4'H_aH_b), 3.88 (s, 3H, CO_2CH_3), 3.87 (s, 3H, CO_2CH_3'), 3.86 (dd, *J* = 9.1, 5.2 Hz, 1H, C2'H_aH_b or C4'H_aH_b), 3.76 (dd, *J* = 9.2, 8.2 Hz, 1H, C2'H_aH_b or C4'H_aH_b), 3.60 (br dd, *J* = 8.7, 5.2 Hz, 1H, C2'H_aH_b or C4'H_aH_b), 3.12 (ddddd, *J* = 10.4, 8.0, 8.0, 5.2, 5.2 Hz, 1H, *H3'*), 1.66 [s, 9H, $C(CH_3)_3$] and 1.42 [s, 9H, $C(CH_3)_3$'].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 166.6, 160.7, 156.4, 153.4, 149.6, 135.7, 134.1, 129.2, 127.7, 126.63, 126.58, 125.0, 123.3, 123.1, 119.3, 117.6, 115.5, 114.6, 114.5, 111.2, 108.0, 86.3 (C≡C-C_{sp3}), 84.3, 79.7, 74.8 (C≡C-C_{sp3}), 59.4 (CH_2O) 53.1 (v br, 2x, *C2'* and *C4'*), 52.9 (OCH_3), 51.8 (OCH_3'), 34.1 (*C3'*), 32.6 (C≡C-C_{sp3}), 28.5, and 28.3.
HSQC
HMBC

IR (neat): 3120, 2977, 2953, 2885, 2235, 1732, 1693, 1385, 1245, 1216, 1156, and 1091 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H^+]: calcd for $C_{38}H_{42}N_3O_{10}^+$, 700.2865; found, 700.2853.

(±)-Dimethyl 1-((Benzyl(*tert*-butoxycarbonyl)amino)(4-methoxyphenyl)methyl)indolizine-2,3-dicarboxylate (96a)



A solution of **91a** (15 mg, 0.07 mmol, 1 equiv), DMAD (20 mg, 0.14 mmol, 2 equiv), *tert*-butyl benzylcarbamate (30 mg, 0.14 mmol, 2 equiv), and DCE (1.5 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 60 °C for 21 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (3:1 hex:EtOAc) to afford **96a** (30 mg, 75%) as a clear colorless oil.

1 mmol scale reaction

A solution of **91a** (0.209 g, 1.0 equiv, 1.0 mmol), DMAD (284 mg, 2.0 mmol, 2.0 equiv), *tert*-butyl benzylcarbamate (0.415 g, 2.0 equiv, 2.0 mmol), and DCE (14 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 64 °C for 21 h. The crude mixture was concentrated under vacuum and purified via flash column chromatography on silica gel (20% ethyl acetate in hexanes) to afford **96a** (412 mg, 74%) as an amorphous white solid.

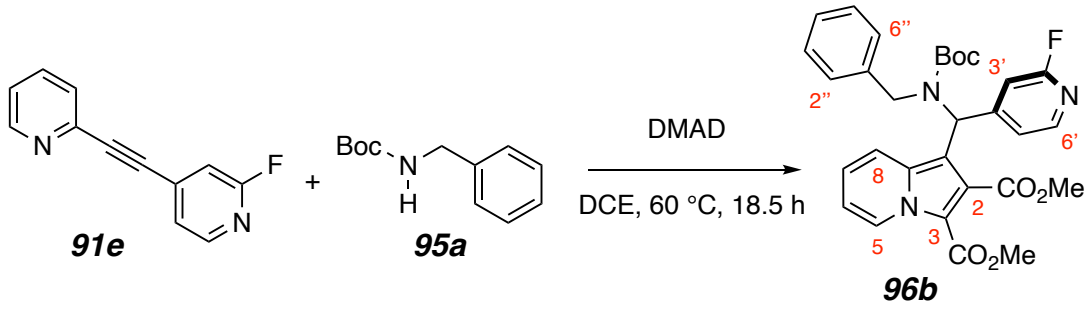
^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.13 (ddd, *J* = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 7.18 (br m, 1H, *H8*), 7.13 (nfod, J_{app} = 8.9 Hz, 2H, *H2'*), 7.00–6.87 (br s, 1H, PMPC*H*N), 6.93 (ddd, *J* = 9.0, 6.7, 1.0 Hz, 1H, *H7*), 6.83 (nfod, J_{app} = 8.8 Hz, 2H, *H3'*), 6.82–6.78 (overlapping m, 3H, *H3"* or *H2"* and *H4"*), 6.75–6.71 (overlapping m, 3H, *H3"* or *H2"* and *H6*), 4.89 (br d, *J* = 15.0 Hz, 1H, NCH_aH_b), 4.46 (br d, *J* = 15.4 Hz, 1H, NCH_aH_b), 3.82 (s, 3H, CO_2CH_3), 3.80 (s, 3H, CO_2CH_3'), 3.55 (s, 3H, C4'OCH_3) and 1.45 (s, 9H, [s, 9H, $OC(CH_3)_3$]).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 166.9, 160.7, 158.7, 156.1, 139.2, 135.8, 131.1, 128.5, 128.1, 127.2, 127.1, 126.3, 125.6, 123.0, 117.9 (br), 114.1, 113.7, 112.2, 110.4, 80.4, 55.4, 54.8, 52.3, 51.6, 48.1, and 28.5.

IR (neat): 3118, 3087, 3062, 3032, 3000, 2975, 2950, 2933, 2836, 1733, 1686, 1511, 1443, 1383, 1245, 1217, 1178, and 1161 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{32}H_{35}N_2O_7^+$, 559.2439; found, 559.2438.

(±)-Dimethyl 1-((Benzyl(*tert*-butoxycarbonyl)amino)(2-fluoropyridin-4-yl)methyl)indolizine-2,3-dicarboxylate (96b)



A solution of **91e** (30 mg, 0.15 mmol, 1 equiv), DMAD (43 mg, 0.30 mmol, 2 equiv), *tert*-butyl benzylcarbamate (47 mg, 0.23 mmol, 1.5 equiv), and DCE (2 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 60 °C for 18.5 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (2:1 hex:EtOAc) to afford **96b** (50 mg, 60%) as a clear colorless oil.

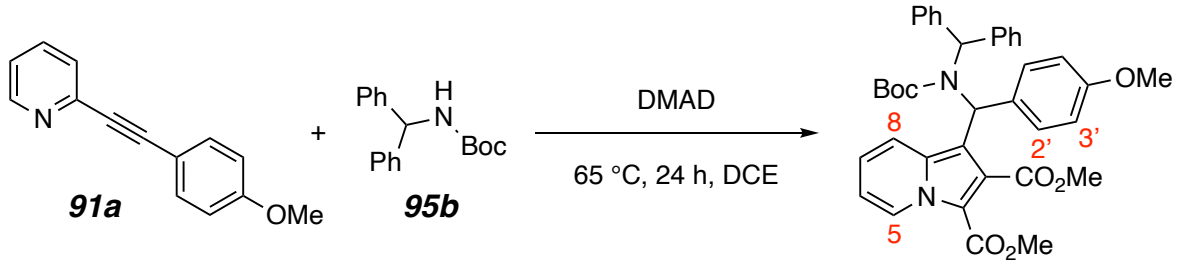
^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.12 (ddd, *J* = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 8.17 (dd, *J* = 5.3, 0.7 Hz, 1H, *H6'*), 7.22 (br m, 1H, *H8*), 7.07–6.94 (br s, 1H, NC*H*), 7.05 (dddd, *J* = 5.2, 1.8, 1.8, 0.9 Hz, 1H, *H5'*), 7.00 (ddd, *J* = 9.0, 6.7, 1.1 Hz, 1H, *H7*), 6.82 (dddd, *J* = 1.5, 1.5, 1.5, 0.6 Hz, 1H, *H3'*), 6.81–6.75 (m, 4H, *H6* & *H3"* & *H4"*), 6.72–6.69 (nfom, 2H, *H2"*), 5.02 (br d, *J* = 14.0 Hz, 1H, NCH_aH$_b$), 4.44 (br d, *J* = 14.0 Hz, 1H, NCH$_a$$H_b$), 3.84 (s, 3H, C3$CO_2CH_3$), 3.52 (s, 3H, C2$CO_2CH_3$), and 1.49 [s, 9H, OC($CH_3$)$_3$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 166.5, 164.3 (d, *J* = 238 Hz), 160.5, 155.9, 155.2 (br), 147.6 (d, *J* = 15 Hz), 138.4, 136.1, 127.9, 127.3, 127.2, 126.1, 125.9, 123.7, 120.1 (d, *J* = 4 Hz), 117.3, 114.4, 111.0, 108.7, 107.9 (d, *J* = 39 Hz), 81.3, 54.3 (br), 52.3, 51.8, 47.9, and 28.4.

IR (neat): 3122, 3088, 3064, 3032, 2977, 2951, 1731, 1684, 1609, 1404, 1382, 1243, 1212, 1158, and 1092 cm^{-1}.

HRMS (ESI-TOF) m/z [M+H$^+$]: calcd for $C_{30}H_{31}FN_3O_6^+$, 548.2191; found, 548.2189.

Dimethyl 1-((Benzhydryl(*tert*-butoxycarbonyl)amino)(4-methoxyphenyl)methyl)indolizine-2,3-dicarboxylate (96c)



A solution of **91a** (1.0 equiv, 25.0 mg, 0.14 mmol) in 1,2-dichloroethane was charged with molecular sieves in a threaded culture tube capped with a Teflon-lined cap. *N*-Boc diphenylmethanamine (**95b**, 2.2 equiv, 89.9 mg, 0.287 mmol) and DMAD (2.0 equiv, 35.1 µL, 0.287 mmol) were added before the reaction solution was heated in an oil bath at 65 °C for 22 hours. The reaction mixture was concentrated, redissolved in EtOAc, and eluted through a silica plug (100% EtOAc). The resulting oil was purified via MPLC (20% EtOAc in hexanes) to afford **96c** (21.5 mg, 28% yield) as a colorless oil.

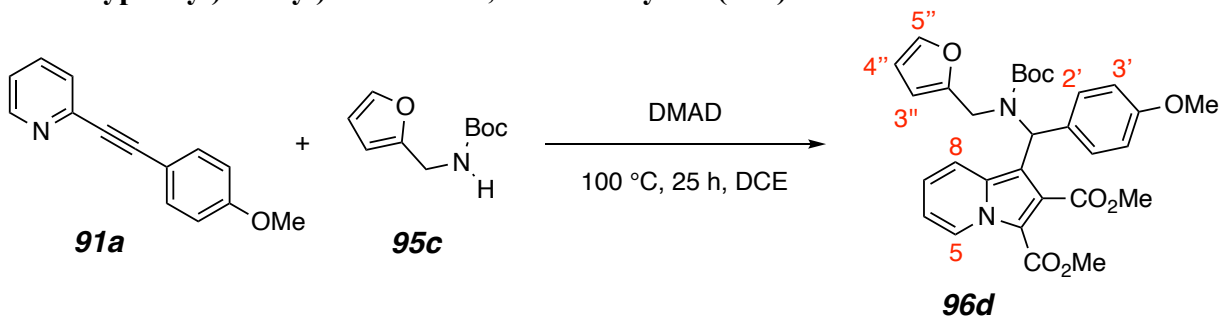
^{1}H NMR (500 MHz, $CDCl_3$): δ 9.17 (ddd, *J* = 7.1, 0.9, 0.9 Hz, 1H, *H5*), 7.32-7.18 (m, ~8H, PMP nfod and phenyl), 7.06 (s, 1H, PMPC*H*), 6.93 (ddd, *J* = 9.1, 6.7, 1.2, 1H, *H7*), 6.90 – 6.84 (m, ~5H), 6.81 (nfod, J_{app} = 9.1 Hz, 2H, *H3'*), 6.76 (ddd, *J* = 7.3, 6.9, 1.4, 1H, *H6*), 5.98 (s, 1H, Ph_2CH), 3.83 (s, 3H, $-CO_2CH_3$), 3.80 (s, 3H, $-CO_2CH_3$'), 3.58 (s, 3H, $ArOCH_3$), and 1.10 (s, 9H, $-C(CH_3)_3$).

^{13}C NMR {^{1}H} (126 MHz, $CDCl_3$): δ 166.9, 160.8, 158.6, 155.9, 142.4, 141.2, 136.3, 131.7, 129.3, 128.80, 128.79, 127.74, 127.72, 127.19, 127.16, 126.5, 125.9, 123.0, 118.5, 114.2, 113.5, 112.1, 110.7, 80.7, 63.8, 57.0, 55.4, 52.5, 51.6, and 28.2.

IR: 2952, 1683, 1510, 1381, 1242, and 699 cm^{-1}

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{38}H_{39}N_2O_7^+$, 635.2752; found, 635.2733.

Dimethyl 1-(((*tert*-butoxycarbonyl)(furan-2-ylmethyl)amino)(4-methoxyphenyl)methyl)indolizine-2,3-dicarboxylate (96d)



A solution of the alkyne **91a** (1.0 equiv, 33.8 mg, 0.174 mmol) in 1,2-dichloroethane was charged with molecular sieves in a threaded culture tube capped with a Teflon-lined cap. *N*-Boc furfurylamine (**95c**, 2.6 equiv, 87.6 mg, 0.44 mmol) and DMAD (1.5 equiv, 26.4 µL, 0.215 mmol) were added before the reaction solution was heated in an oil bath at 100 °C for 25 hours. The reaction mixture was concentrated, redissolved in EtOAc, and passed through a silica plug (eluted with 100% EtOAc). The resulting oil was purified via MPLC (20% EtOAc in hexanes) to afford the indolizine derivative **96d** (38.1 mg, 61% yield) as a brown oil.

^{1}H NMR (500 MHz, $CDCl_3$): 9.35 (ddd, *J* = 7.2, 1.1, 1.1 Hz, *H5*), 7.30–7.21 (br m, *H8*), 7.11 (nfod, J_{app} = 8.5 Hz, 2H, *H2'*), 7.0–6.9 (br m, 1H, NC*H*PMP), 6.98 (ddd, *J* = 9.1, 6.6, 1.1, *H7*), 6.86–6.81 (overlapping m's, 4H, H6, H3', and H5''), 5.86 (dd, *J* = 3.2, 1.9 Hz, H4''), 5.49–5.44 (br m, *H3''*), 4.66 (d, *J* = 16.3 Hz, 1H, NCH_aH$_b$), 4.50 (d, *J* = 16.3 Hz, 1H, NCH$_a$$H_b$), 3.84 (s, 3H, -$CO_2CH_3$), 3.80 (s, 3H, -$OCH_3$), 3.55 (s, 3H, -$CO_2CH_3$'), and 1.45 [s, 9H, -$OC(CH_3)_3$].

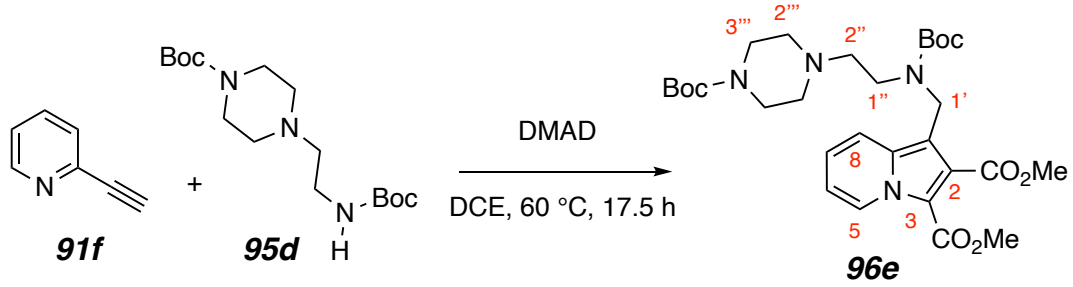
^{1}H NMR (500 MHz, C_6D_6): 9.42 (ddd, *J* = 7.1, 1.1, 1.1 Hz, 1H, *H5*), 7.43–7.34 (br s, 1H, NC*H*PMP or *H8*), 7.30–7.23 (br s, 1H, NC*H*PMP or *H8*), 7.20 (nfod, J_{app} = 8.3 Hz, 2H, *H2'*), 6.74 (nfod, J_{app} = 8.6 Hz, 2H, *H3'*), 6.70 (dd, *J* = 1.8, 1.0 Hz, 1H, *H5''*), 6.36 (ddd, *J* = 9.1, 6.8, 1.3 Hz, 1H, *H7*), 6.15 (ddd, *J* = 7.2, 6.7, 1.4 Hz, 1H, *H6*), 5.74 (dd, *J* = 3.1, 1.8 Hz, 1H, *H4''*), 5.73–5.68 (br m, 1H, *H3''*), 4.90 (d, *J* = 16.3 Hz, 1H, NCH_aH$_b$), 4.82 (d, *J* = 16.3 Hz, 1H, NCH$_a$$H_b$), 3.50 (s, 3H, -$CO_2CH_3$), 3.48 (s, 3H, -$CO_2CH_3$'), 3.31 (s, 3H, -$OCH_3$), and 1.48 [s, 9H, -$C(CH_3)_3$].

^{13}C NMR {^{1}H} (126 MHz, $CDCl_3$): δ 167.0, 160.9, 158.8, 155.8, 152.7, 140.6, 136.0, 131.0, 128.5, 128.2, 127.3 123.0, 118.0, 114.3, 113.7, 112.2, 110.4, 109.6, 105.6, 80.5, 55.4, 52.4, 51.6, 41.5, and 28.5.

IR: 2925, 1733, 1685, 1380, 1213, 1089, 746, and 598 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H]: calcd for $C_{30}H_{33}N_2O_8^+$, 549.2231; found, 549.2215.

Dimethyl 1-(((*tert*-Butoxycarbonyl)(2-(4-(*tert*-butoxycarbonyl)piperazin-1-yl)ethyl)amino)methyl)indolizine-2,3-dicarboxylate (96e)



91f + ***95d*** → ***96e***

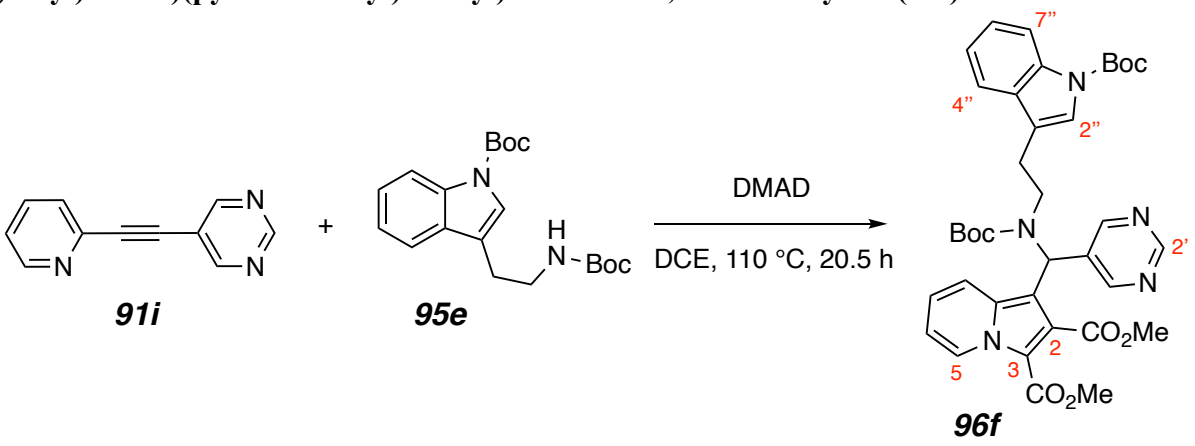
A solution of 2-ethynylpyridine (20 mg, 0.19 mmol, 1 equiv), DMAD (43 mg, 0.30 mmol, 1.6 equiv), *tert*-butyl 4-(2-((*tert*-butoxycarbonyl)amino)ethyl)piperazine-1-carboxylate[33] (76 mg, 0.23 mmol, 1.2 equiv), and DCE (2 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 60 °C for 17.5 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (1:1 hex:EtOAc) to afford **96e** (45 mg, 40%) as a yellow oil.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.39 (ddd, *J* = 7.2, 1.0, 1.0 Hz, 1H, *H5*), 7.88–7.59 (br m, 1H, *H8*), 7.09 (ddd, *J* = 9.0, 6.7, 1.0 Hz, 1H, *H7*), 6.91 (ddd, *J* = 7.2, 6.7, 1.4 Hz, 1H, *H6*), 4.67 (s, 2H, C1'H_2), 3.94 (s, 3H, CO_2CH_3), 3.89 (s, 3H, CO_2CH_3'), 3.44–3.30 (br m, 4H, *H3'''*), 3.27–3.17 (br m, 2H, *H1''*), 2.46–2.29 (br m, 6H, *H2''* & *H2'''*), 1.50 [s, 9H, $OC(CH_3)_3$], and 1.45 [s, 9H, $OC(CH_3)_3$].
^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 167.0, 160.8, 155.8, 154.8, 135.8, 127.9, 127.4, 122.9, 118.7, 114.7, 110.6, 110.2, 79.9, 79.7, 56.2, 53.1, 52.7, 51.7, 43.8 (br), 42.6, 39.8, 28.6, and 28.5.

IR (neat): 3002, 2975, 2951, 2865, 2811, 1733, 1683, 1416, 1382, 1364, 1216, 1149, and 1129 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{29}H_{43}N_4O_8^+$, 575.3075; found, 575.3072.

(±)-Dimethyl 1-(((*tert*-Butoxycarbonyl)(2-(1-(*tert*-butoxycarbonyl)-1*H*-indol-3-yl)ethyl)amino)(pyrimidin-5-yl)methyl)indolizine-2,3-dicarboxylate (96f)



91i *95e* ***96f***

A solution of 5-(pyridin-2-ylethynyl)pyrimidine (**91g**, 25 mg, 0.14 mmol, 1 equiv), the tryptamine derivative[34] **95e** (99 mg, 0.27 mmol, 2 equiv), DMAD (59 mg, 0.29 mmol, 3 equiv), and DCE (1.5 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 110 °C for 20.5 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (1:2 hex:EtOAc) to afford **96f** (52 mg, 55%) as an orange oil.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.36 (ddd, *J* = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 9.13 (d, *J* = 0.8 Hz, 1H, *H2'*), 8.54 (d, *J* = 1.0 Hz, 2H, *H4'/6'*), 7.97–7.82 (br s, 1H, *H7"*), 7.37–7.23 (br s, 1H, *H2"*), 7.18–6.91 (br s, 1H, NC*H*), 7.17 (nfom, 1H, *H6"*), 7.09 (ddd, *J* = 9.1, 6.7, 1.1 Hz, 1H, *H7*), 7.03–6.96 (m, 3H, *H8*, *H4"*, *H5"*), 6.93 (ddd, *J* = 7.2, 6.8, 1.4 Hz, 1H, *H6*), 3.86 (s, 3H, $C3CO_2C\mathit{H}_3$), 3.83 (ddd, *J* = 14.1, 9.4, 4.7 Hz, 1H, $NC\mathit{H}_aH_b$), 3.71 (br m, 1H, $NCH_a\mathit{H}_b$), 3.51 (s, 3H, $C2CO_2C\mathit{H}_3$), 2.71 (br m, 1H, $NCH_2C\mathit{H}_aH_b$), 2.21 (br s, 1H, $NCH_2CH_a\mathit{H}_b$), 1.64 [s, 9H, $C(C\mathit{H}_3)_3$], and 1.55 [s, 9H, $C(C\mathit{H}_3)_3$].

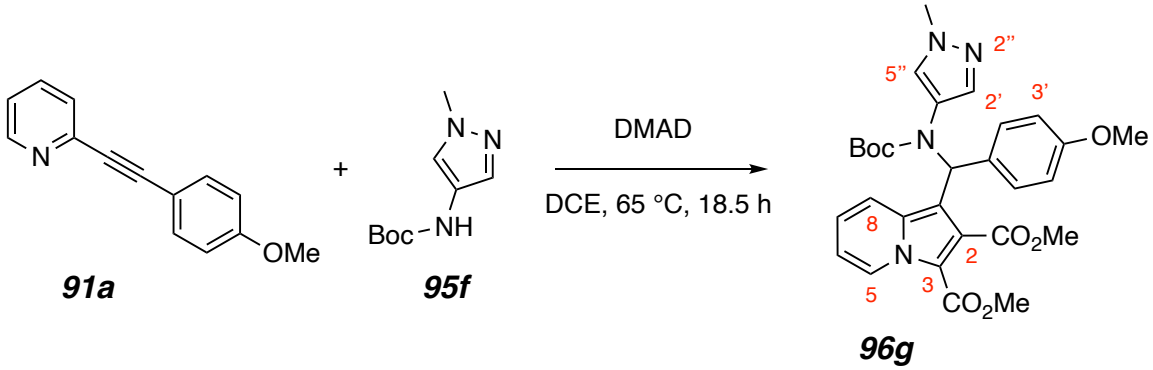
^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 166.3 ($C2\mathit{C}O_2CH_3$), 160.4 ($C3\mathit{C}O_2CH_3$), 157.6 (*C2'*), 155.8 (x2, *C4'/6'* and $CH_2N\mathit{C}$=O), 149.6 (N1*C*=O), 135.6, 135.1, 133.3 (*C5'*), 130.1, 128.3, 127.8, 124.1 (*C6"*), 124.0, 123.2, 122.1, 118.6, 117.5, 117.0 (*C2"*), 115.1 (*C7"*), 114.8, 111.5, 108.7, 83.3 ($O\mathit{C}Me_3$), 81.2 ($O\mathit{C}Me_3$'), 52.5($C2CO_2\mathit{C}H_3$), 51.81 ($C3CO_2\mathit{C}H_3$ or N*C*H), 51.79 ($C3CO_2\mathit{C}H_3$ or N*C*H), 45.4 ($N\mathit{C}H_2$), 28.6 ($OC\mathit{C}H_3$), 28.3 ($OC\mathit{C}H_3$'), and 24.7 ($NCH_2\mathit{C}H_2$).

HSQC
HMBC
NOESY

IR (neat): 3046, 2977, 2953, 2934, 1713, 1692, 1453, 1384, 1254, 1216, and 1160 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{37}H_{42}N_5O_8^+$, 684.3028; found, 684.3017.

(±)-Dimethyl 1-(((*tert*-Butoxycarbonyl)(1-methyl-1*H*-pyrazol-4-yl)amino)(4-methoxyphenyl)methyl)indolizine-2,3-dicarboxylate (96g)



A solution of 2-((4-methoxyphenyl)ethynyl)pyridine[31] (30 mg, 0.14 mmol, 1.0 equiv), DMAD (41 mg, 0.29 mmol, 2.0 equiv), *tert*-butyl (1-methyl-1*H*-pyrazol-4-yl)carbamate[35] (57 mg, 0.29 mmol, 2.0 equiv), and DCE (2 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 65 °C for 18.5 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (1:1 hex:EtOAc) to afford **96g** (29 mg, 37%) as an orange oil.

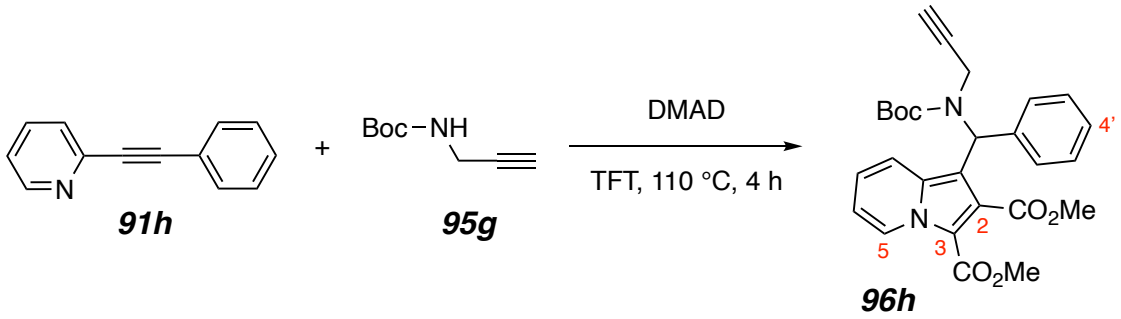
^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.33 (ddd, *J* = 6.7, 1.6, 1.2 Hz, 1H, *H5*), 7.24 (nfod, J_{app} = 9.0 Hz, 2H, *H2'*), 7.02 (s, 1H, *H3"*), 7.01 (br s, 1H, NC*H*), 6.88 (nfod, J_{app} = 9.0 Hz, 2H, *H3'*), 6.86 (s, 1H, *H5"*), 6.73 (ddd, *J* = 6.6, 6.6, 1.6 Hz, 1H, *H6*), 6.70 (ddd, *J* = 8.9, 6.7, 1.2 Hz, 1H, *H7*), 6.35 (ddd, *J* = 8.8, 1.6, 1.0 Hz, 1H, *H8*), 3.88 (s, 3H, CO_2CH_3), 3.86 (s, 3H, CO_2CH_3'), 3.82 (s, 3H, C4'OCH_3), 3.54 (s, 3H, NCH_3), and 1.42 [s, 9H, OC(CH_3)$_3$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 166.8, 160.9, 158.8, 155.1, 138.0, 135.6, 131.3, 129.3, 128.2, 128.1, 127.4, 122.3, 121.8, 118.9, 114.0, 111.7, 110.3, 80.8, 57.1, 55.4, 52.8, 51.7, 39.1, and 28.4. (the resonance for one sp^2-hydridized carbon atom was not observed in either the 1D or 2D ^{13}C spectra)

IR (neat): 3118, 2977, 2952, 2839, 1735, 1691, 1510, 1381, 1246, 1215, and 1176 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{29}H_{33}N_4O_7^+$, 549.2344; found, 549.2342.

Dimethyl 1-(((*tert*-Butoxycarbonyl)(prop-2-yn-1-yl)amino)(phenyl)methyl)indolizine-2,3-dicarboxylate (96h)



A solution of 2-(phenylethynyl)pyridine (**91h**, 22 mg, 0.12 mmol, 1 equiv), *N*-Boc-propargylamine (38 mg, 0.24 mmol, 2 equiv), DMAD (52 mg, 0.37 mmol, 3 equiv), and TFT (1.5 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 110 °C for 4 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (4:1 hex:EtOAc) to afford **96h** (44 mg, 75%) as an amorphous white solid.

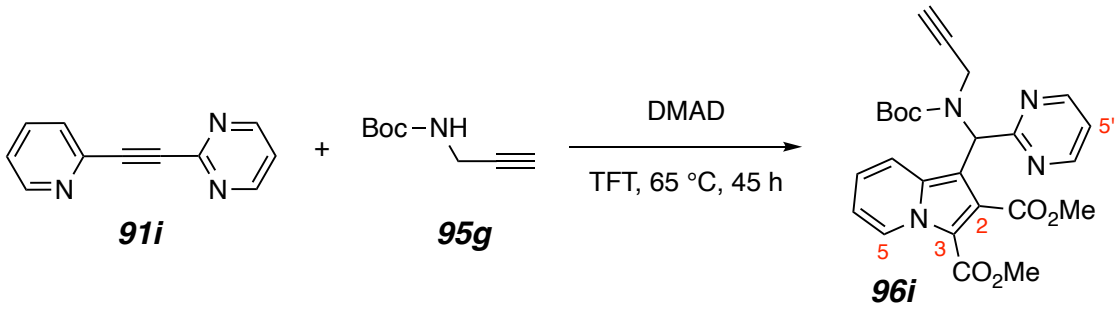
^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.44 (ddd, *J* = 7.2, 1.2, 1.2 Hz, 1H, *H5*), 7.45–7.35 (br m, *H8*), 7.34–7.30 (nfodd, J_{app} = 7.9, 7.2 Hz, 2H, *H3'/5'*), 7.28–7.24 (m, 3H, *H2'/6'*and *H3'*), 7.07 (ddd, *J* = 9.0, 6.7, 1.0 Hz, 1H, *H7*), 7.10–6.95 (br m, NC*H*Ar), 6.90 (ddd, *J* = 7.3, 6.7, 1.3 Hz, 1H, *H6*), 4.15 (dd, *J* = 17.7, 2.4 Hz, 1H, NCH_aH_b), 4.10 (dd, *J* = 17.8, 2.4 Hz, 1H, NCH_aH_b), 3.84 (s, 3H, $C3CO_2CH_3$), 3.47 (s, 3H, $C2CO_2CH_3$), 1.61 (dd, *J* = 2.2, 2.2 Hz, 1H, C≡C-*H*), and 1.49 [s, 9H, $C(CH_3)_3$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 166.7, 160.9, 155.3, 138.7, 136.5, 128.35, 128.31, 127.5, 127.32, 127.27, 123.3, 118.2, 114.5, 111.2, 110.8, 80.9, 80.6, 69.1, 55.2 (br), 52.3, 51.6, 34.4, and 28.4.

IR (neat): 3283, 2977, 2951, 1732, 1690, 1497, 1443, 1383, 1246, 1218, 1163, and 1094 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{27}H_{29}N_2O_6^+$, 477.2020; found, 477.2004.

(±)-Dimethyl 1-(((*tert*-Butoxycarbonyl)(prop-2-yn-1-yl)amino)(pyrimidin-2-yl)methyl)indolizine-2,3-dicarboxylate (96i)



A solution of 2-(pyridin-2-ylethynyl)pyrimidine (**91i**, 26 mg, 0.14 mmol, 1 equiv), *N*-Boc-propargylamine (44 mg, 0.28 mmol, 2 equiv), DMAD (41 mg, 0.29 mmol, 2 equiv), and TFT (1.5 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 65 °C for 45 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (1:1 hex:EtOAc) to afford **96i** (22 mg, 32%) as a clear colorless oil.

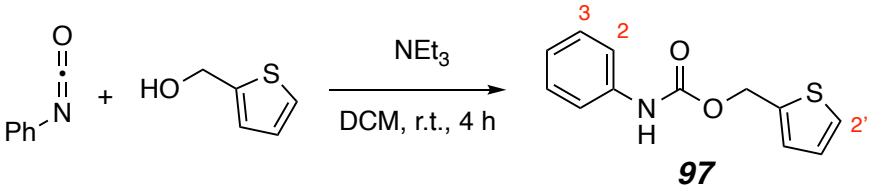
^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.42 (ddd, *J* = 7.2, 1.2, 1.2 Hz, 1H, *H5*), 8.72 (d, *J* = 4.9 Hz, 2H, *H4'/6'*), 7.75–7.56 (br s, 1H, *H8*), 7.33–7.10 (br s, 1H, NC*H*ArAr'), 7.21 (td, *J* = 4.9, 0.5 Hz, 1H, *H5'*), 7.15 (ddd, *J* = 9.0, 6.8, 1.2 Hz, 1H, *H7*), 6.92 (ddd, *J* = 7.1, 6.8, 1.3 Hz, 1H, *H6*), 4.42 (br m, 1H, NCH_aH$_b$), 4.22 (br m, 1H, NCH$_a$$H_b$), 3.82 (s, 3H, C3$CO_2CH_3$), 3.52 (br s, 3H, C2$CO_2CH_3$), and 1.65–1.31 [m, 10H, OC(CH_3)$_3$ and C≡C-*H*].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 168.2 (br, *C1'*), 166.5 (C2*C*O_2Me), 160.9 (C3*C*O_2Me), 157.2 (*C4'*), 137.0, 127.38 (*C5*), 127.37, 123.5 (*C7*), 119.6 (*C5'*), 118.2 (br, *C8*), 114.7 (*C6*), 111.2 (*C3*), 80.93 (br), 80.89, 68.3 (br), 56.4 (br, NCHArAr'), 52.3 (C2CO_2CH$_3$), 51.6 (C3CO_2CH$_3$), 34.8 (br, C≡C-*C*H$_2$), and 28.5 [OC(*C*H$_3$)$_3$].
HSQC
HMBC
(two carbon resonances, likely for the Boc-carbonyl and indolizine C1 carbons were not observed)

IR (neat): 3278, 3039, 2976, 2952, 1731, 1686, 1565, 1383, 1244, and 1163 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{25}H_{27}N_4O_6^+$, 479.1925; found, 479.1910.

Thiophen-2-ylmethyl phenylcarbamate (97)



97

To a solution of thiophen-2-ylmethanol (0.83 mL, 8.86 mmol, 1 equiv) in DCM (10 mL) was add phenyl isocyanate (1.06 mL, 9.75 mmol, 1.1 equiv) and NEt_3 (2.4 mL, 17.2 mmol, 1.9 equiv). The solution was stirred at room temperature for 4 h. Water was added and the crude product was extracted with EtOAc. The organic layer was washed with brine, dried with $MgSO_4$, and concentrated under vacuum. The sample was purified by a crystallization in which hexanes was added dropwise to a solution of the crude reaction mixture dissolved in DCM. This afforded **97** (1.29 g, 80%) as a white crystalline solid.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.37 (br m, 2H, *H2*), 7.33 (dd, *J* = 5.1, 1.3 Hz, 1H, *H2'*), 7.30 (nfodd, *J* = 7.5, 7.5 Hz, 2H, *H3*), 7.14 (ddt, *J* = 3.5, 1.4, 0.8 Hz, 1H, *H4'*), 7.06 (tt, *J* = 7.3, 1.2 Hz, 1H, *H4*), 7.00 (dd, *J* = 5.1, 3.5 Hz, 1H, *H3'*), 6.65 (br s, 1H, N*H*), and 5.35 (d, *J* = 0.8 Hz, 2H, OCH_2).

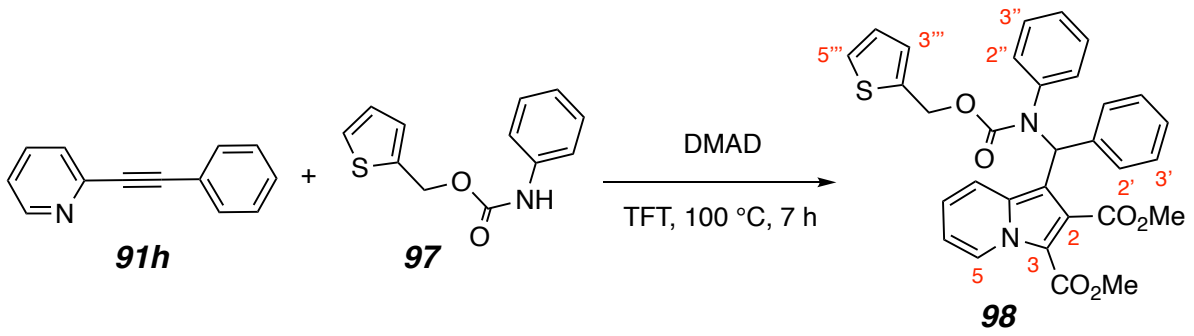
^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 153.2, 138.1, 137.8, 129.2, 128.5, 127.13, 127.05, 123.8, 118.9, and 61.3.

IR (neat): 3276, 3197, 3140, 3107, 3088, 1691, 1600, 1547, 1445, 1315, 1233, 1217, and 1057 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{12}H_{12}NO_2S^+$, 234.0583; found, 234.0577.

mp: 71–73 °C.

Dimethyl 1-(Phenyl(phenyl((thiophen-2-ylmethoxy)carbonyl)amino)methyl)indolizine-2,3-dicarboxylate (98)



A solution of 2-(phenylethynyl)pyridine (15 mg, 0.08 mmol, 1 equiv), thiophen-2-ylmethyl phenylcarbamate (**97**, 39 mg, 0.17 mmol, 2 equiv), DMAD (23 mg, 0.16 mmol, 2 equiv), and TFT (1 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 100 °C for 7 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (3:1 hex:EtOAc) to afford **98** (28 mg, 60%) as a clear colorless oil.

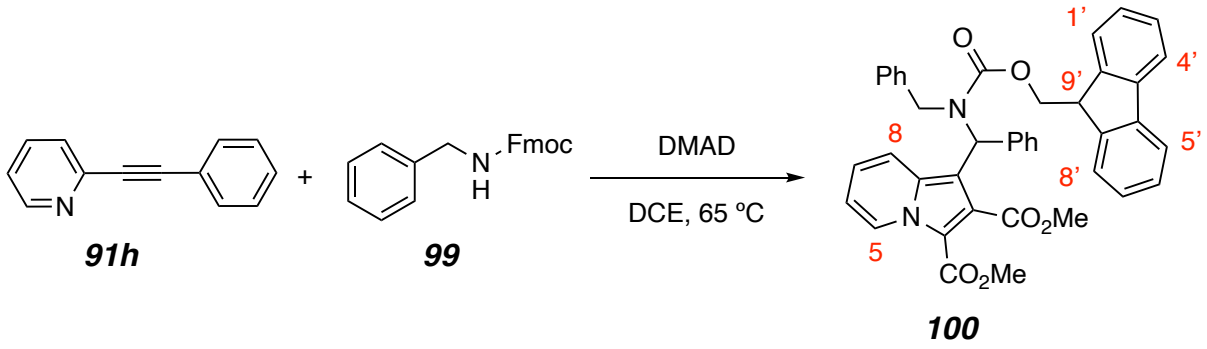
^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.27 (ddd, *J* = 7.2, 1.2, 1.2 Hz, 1H, *H5*), 7.38 (nfod, J_{app} = 8.5 Hz, 2H, *H2'*), 7.33 (nfodd, J_{app} = 8.0 Hz, 2H, *H3'*), 7.28 (nfom, 1H, *H4'*), 7.26 (dd, *J* = 5.1, 1.3 Hz, 1H, *H5'''*), 7.07 (dt, *J* =1.0, 1.0, 1.0 Hz, 1H, NC*H*), 6.982 (dd, *J* = 3.2, 1.2 Hz, 1H, *H3'''*), 6.979 (s, 5H, *H2''–H6''*), 6.93 (d, *J* = 5.1, 3.4 Hz, 1H, *H4'''*), 6.65 (ddd, *J* = 7.0, 6.5, 1.3 Hz, 1H, *H6*), 6.54 (ddd, *J* = 9.1, 6.7, 1.2 Hz, 1H, *H7*), 6.24 (ddd, *J* = 9.1, 1.3, 1.3 Hz, 1H, *H8*), 5.31 (dd, *J* = 12.9, 0.7 Hz, 1H, OCH_aH_b), 5.27 (dd, *J* = 12.9, 0.8 Hz, 1H, OCH_aH_b), 3.88 (s, 3H, $C3CO_2CH_3$), and 3.76 (s, 3H, $C2CO_2CH_3$').

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 166.7 ($C2CO_2Me$), 160.9 ($C3CO_2Me$'), 155.6 (NC=O), 140.0 (*C1''*), 139.10 (*C1'* or *C2'''*), 139.08 (*C1'* or *C2'''*), 135.6 (*C9*), 129.6 (*C2*), 129.4 (*C4'*), 128.6 [*C3'* and (*C2''* or *C3''*)], 128.4 (*C2''* or *C3''*), 127.6 (*C3'''*), 127.27 (*C5* or *C4'*), 127.25 (*C5* or *C4'*), 127.2 (*C2'*), 126.7 (*C4'''*), 126.5 (*C5'''*), 122.1 (*C7*), 119.3 (*C8*), 113.9 (*C6*), 110.6 (*C1* or *C3*), 110.3 (*C1* or *C3*), 62.1 ($C2'''CH_2$), 59.0 (PhCHN), 52.7 ($C2CO_2CH_3$), and 51.7 ($C3CO_2CH_3$).
HSQC, HMBC

IR (neat): 3113, 3060, 3028, 2951, 1736, 1695, 1495, 1441, 1383, 1214, and 1088 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{31}H_{27}N_2O_6S^+$, 555.1584; found, 555.1574.

Dimethyl 1-(((((9*H*-Fluoren-9-yl)methoxy)carbonyl)(benzyl)amino)(phenyl)methyl)indolizine-2,3-dicarboxylate (100)



91h + ***99*** → ***100***

The alkyne **91h** (1.0 equiv, 53.8 mg, 0.30 mmol) and the carbamate **99** (2.0 equiv, 0.204 g, 0.61 mmol) were dissolved in DCE containing molecular sieves (2.0 mL) in a threaded culture tube. The tube was sealed with a Teflon-lined cap, DMAD (2.0 equiv, 85.3 µL, 0.60 mmol) was added, and the reaction mixture was heated to 65 °C for 20 h. The reaction mixture was filtered through a silica plug eluted with ethyl acetate and purified via MPLC (silica gel, 20% EtOAc in hexanes) to afford the indolizine **100** as a crystalline white solid (84.2 mg, 58%).

^{1}H NMR (500 MHz, $CDCl_3$): δ 9.09 (ddd, *J* = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 7.75–7.65 (br s, 2H),7.57–6.53 (br multiplets, ca. 20H),5.20–5.00 (br s, 0.56H, PhCH_aH$_b$, major rotamer), 5.00–4.81 (br s, 0.51H, PhCH_aH$_b$, minor rotamer), 4.78–4.42 (br m, 3H, PhCH$_a$$H_b$ and OC$H_a$$H_b$), 4.25–4.15 (br s, 1H, *H9'*), 3.81 (s, 3H, C3CO_2CH_3), and 3.39 (s, 3H, C2CO_2CH_3).

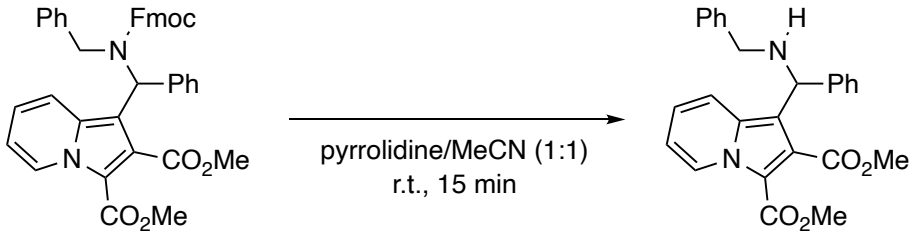
^{13}C NMR {^{1}H} (126 MHz, $CDCl_3$): δ 166.7 (br), 160.7, 157.0 (br), 144.0 (br), 141.5, 138.6,* 138.2,* 128.5, 128.2 (br), 127.7 (br), 127.3 (br), 127.2 (br), 127.14 (br), 127.10, 126.3 (v br), 125.7, 125.2, 125.0 (br), 123.2, 120.0 (br), 114.2, 110.6, 67.7, 55.5, 52.3, 51.6, 48.3 (v br), and 47.6.
*observable only by HMBC; broad resonances for the two Ph carbons bearing the benzylic carbons.
(one aromatic carbon not discernable due to the amide rotamers as well as 'slowish' rotation about the C1–C(Ph)N carbon-carbon bond; see the following, Fmoc-deprotected amine in which a full set of resonances is observed in both the proton and carbon spectra.)

IR (neat): 2949, 1730, 2687, 1243, 1213, and 1093 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H]: calcd for $C_{41}H_{35}N_2O_6^+$, 651.2490; found, 651.2509.

mp: 104–107 ºC.

Dimethyl 1-((Benzylamino)(phenyl)methyl)indolizine-2,3-dicarboxylate (101)



100 ***101***

The indolizine derivative **100** (1.0 equiv, 89 mg, 0.14 mmol) was dissolved in a 1:1 mixture of pyrrolidine and acetonitrile (4 mL). The reaction mixture was stirred at rt for 10 minutes before it was partitioned into Et_2O and DI H_2O. The aqueous layer was extracted with Et_2O. The combined organic layers were dried with $MgSO_4$. The crude material was purified via MPLC (10% EtOAc in hexanes) to afford the indolizine **101** as a yellow oil (44.3 mg, 74%).

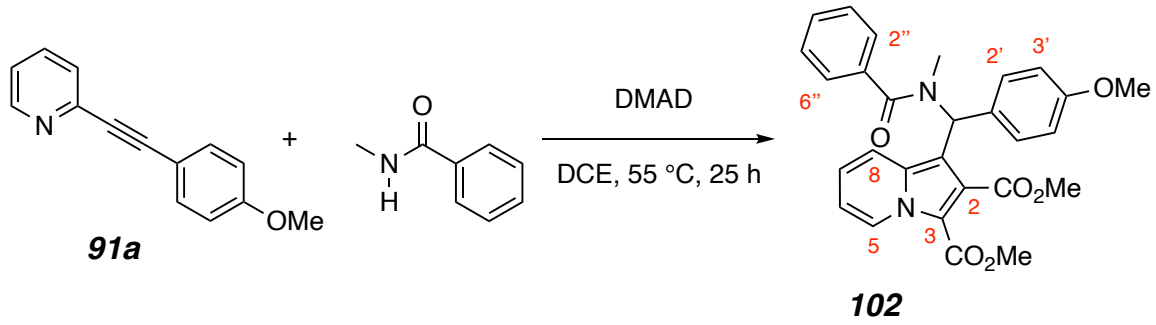
^{1}H NMR (500 MHz, $CDCl_3$): δ 9.38 (ddd, *J* = 7.3, 1.1, 1.1 Hz, 1H, *H5*), 7.72 (ddd, *J* = 9.1, 1.3, 1.3 Hz, 1H, *H8*), 7.51 (nfod, J_{app} = 7.4 Hz, 2H, PhH_o), 7.31–7.22 (m, 7H, PhHs), 7.19 (tt, *J* = 7.3, 1.3 Hz, 1H, Ph'H_p), 6.99 (ddd, *J* = 8.9, 6.8, 1.1 Hz, 1H, *H7*), 6.84 (ddd, *J* = 6.9, 1.4, 1.4 Hz, 1H, *H6*), 5.20 (s, 1H, C*H*N), 3.87 (s, 3H, CO_2CH_3), 3.81 (s, 3H, CO_2CH_3), 3.79 (d, *J* = 13.4 Hz, 1H, CH_aH$_b$Ph), and 3.79 (d, *J* = 13.4 Hz, 1H, CH$_a$$H_b$Ph).
(The N*H* resonance was unable to be definitively identified.)

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 167.8, 160.9, 143.0, 140.5, 134.6, 128.5, 128.5, 128.3, 127.5, 127.4, 127.2, 127.0, 126.9, 122.4, 118.9, 115.9, 114.3, 110.3, 58.7, 52.6, 52.2, and 51.6.

IR (neat): 2950, 1731, 1686, 1381, 1211, 1090, and 698 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H]: calcd for $C_{26}H_{25}N_2O_4^+$, 429.1809, found 429.1786.

(±)-Dimethyl 1-((4-Methoxyphenyl)(*N*-methylbenzamido)methyl)indolizine-2,3-dicarboxylate (102)



A solution of **91a** (30 mg, 0.14 mmol, 1 equiv), DMAD (41 mg, 0.29 mmol, 2 equiv), *N*-methylbenzamide (39 mg, 0.29 mmol, 2 equiv), and DCE (2 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 55 °C for 25 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (1.5:1 hex:EtOAc) to afford **102** (60 mg, 86%) as a yellow oil.

Because of the dynamic features in this molecule caused by the tertiary amide rotamers and rotation around the hindered C1–C(N) bond, a chiral axis, the NMR data could not be fully interpreted. The compound **102-H** on the following page, the analog lacking the PMP substituent, was synthesized. Its NMR data were more discernable and those spectral properties were used along with HMBC and HSQC correlations to make the following assignments:

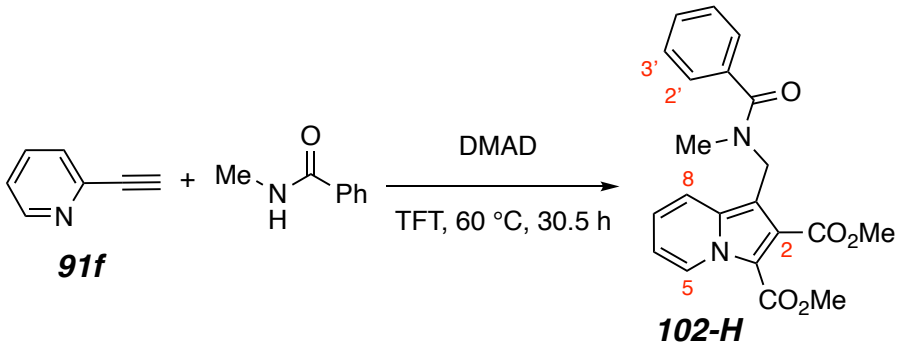
^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.46 (br s, 1H, *H5*), 7.50 (br s, overlapped, ArC*H*(N)$_{\text{major rotamer}}$ (from HSQC)), 7.49–6.68 (br overlapping multiplets, ca. 10H), 6.91 (nfod, J_{app} = 8.7 Hz, 2H, *H3'*), 6.44 (br s, 0.34H, ArC*H*(N)$_{\text{minor rotamer}}$), 3.87 (br s, 3H, CO_2CH_3), 3.84 (br s, 3H, CO_2CH_3'), 3.87 (s, 2H, C3CO_2CH_3), 3.87 (s, 2H, C3CO_2CH_3), 3.84 (br s, 3H, ArOCH_3), 3.66 (br s, 2.1H, C2$CO_2CH_{3\text{-major rotamer}}$), 3.55 (br s, 1.0H, C2$CO_2CH_{3\text{-minor rotamer}}$), 2.99 (br s, 1.2H, N$CH_{3\text{-minor rotamer}}$), and 2.80 (br s, 1.9H, N$CH_{3\text{-major rotamer}}$).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 172.2 (br O=*C*N$_{\text{minor rotamer}}$), 171.6 (br O=*C*N$_{\text{major rotamer}}$), 166.8 (br, C3*C*O_2Me$_{\text{major rotamer}}$), 166.5 (br, C3*C*O_2Me$_{\text{minor rotamer}}$), 160.7 (C3*C*O_2Me), 159.2–158.8 (br, C4'), 136.6 (br), 136.2 (br), 135.9 (br), 135.2 (br), 130.9 (br), 130.1 (br), 129.7 (br), 129.4 (br), 129.0 (br),128.7 (br), 128.5 (br), 128.1 (br), 127.7, 127.0, 123.4, 118.3 (br), 117.9 (br), 114.4, 114.1, 110.9 (br), 110.8 (br), 59.0 (br, Ar*C*(N)$_{\text{minor rotamer}}$), 55.5 ArO*C*H_3), 53.0 (C2*C*=O), 52.7 (C2*C*=O), 52.6 (br, Ar*C*(N)$_{\text{major rotamer}}$), 51.7 (C3*C*=O), 34.7, and 31.1.

IR (neat): 3116, 3026, 2998, 2951, 2930, 2837, 2238, 1734, 1691, 1629, 1510, 1381, 1243, 1213, and 1159 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{28}H_{27}N_2O_6^+$, 487.1864; found, 487.1865.

Dimethyl 1-((*N*-Methylbenzamido)methyl)indolizine-2,3-dicarboxylate (102-H)



91f ***102-H***

A solution of 2-ethynylpyridine (20 mg, 0.19 mmol, 1 equiv), DMAD (55 mg, 0.39 mmol, 2 equiv), *N*-methylbenzamide (52 mg, 0.38 mmol, 2 equiv), and TFT (1.5 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 60 °C for 30.5 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (1.5:1 hex:EtOAc) to afford **102-H** (27 mg, 37%) as a yellow oil.

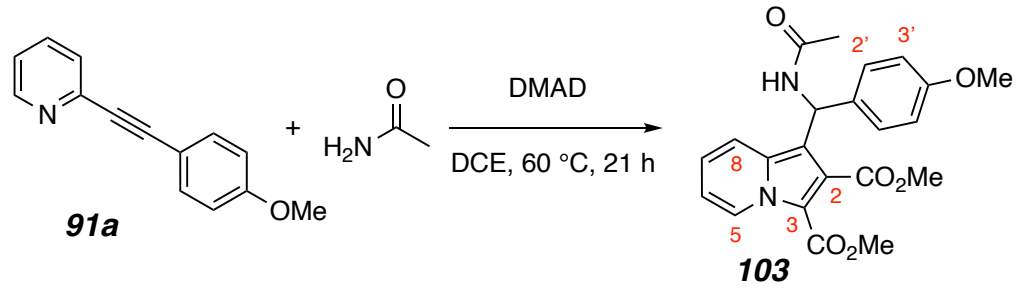
^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.41 (ddd, *J* = 7.0, 1.0, 1.0 Hz, 1H, *H5*), 7.94 (br d, *J* = 8.9 Hz, 1H, *H8*), 7.62–7.33 (m, 5H, -C_6H_5), 7.14 (br m, 1H, *H7*), 6.93 (br dd, *J* = 7.1, 7.1 Hz, 1H, *H6*), 5.01–4.70 (br s, 2H, NCH_2), 3.96 (s, 3H, CO_2CH_3), 3.90 (s, 3H, CO_2CH_3'), and 2.96–2.76 (br s, 3H, NCH_3).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 171.4, 167.0, 160.9, 136.4, 135.9, 129.7, 128.5, 128.3, 127.4, 127.0, 123.3, 118.6, 114.8, 110.5, 109.3, 52.9, 51.8, 40.1, and 36.6.

IR (neat): 3118, 3025, 2951, 1732, 1690, 1628, 1500, 1443, 1384, 1218, and 1095.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{21}H_{21}N_2O_5^+$, 381.1445; found, 381.1435.

(±)-Dimethyl 1-(Acetamido(4-methoxyphenyl)methyl)indolizine-2,3-dicarboxylate (103)



A solution of **91a** (15 mg, 0.07 mmol, 1 equiv), DMAD (20 mg, 0.14 mmol, 2 equiv), acetamide (20 mg, 0.35 mmol, 5 equiv), and DCE (1.5 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 60 °C for 21 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (1:1.5 hex:EtOAc) to afford **103** (16 mg, 54%) as a yellow oil.

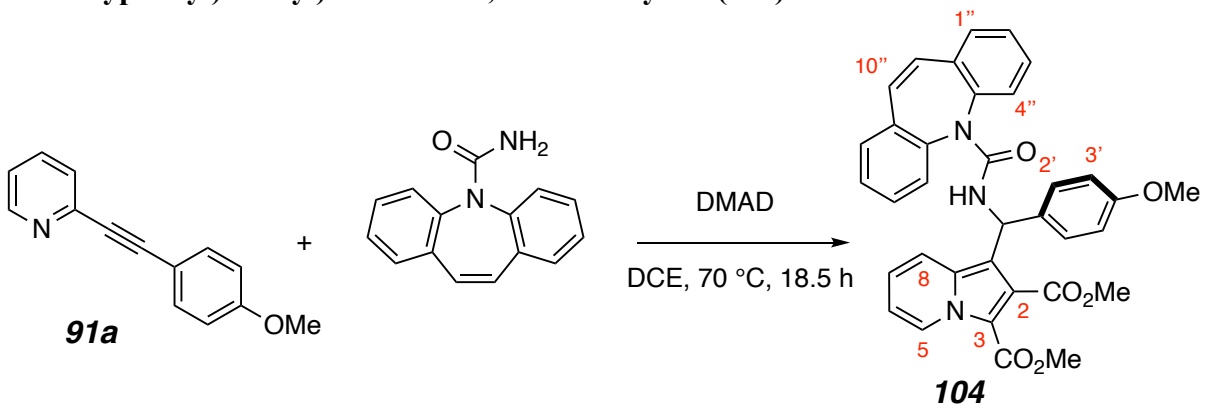
^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.35 (ddd, *J* = 7.2, 1.2, 1.2 Hz, 1H, *H5*), 7.74 (ddd, *J* = 9.1, 1.2, 1.2 Hz, 1H, *H8*), 7.13–7.10 (overlapping m, 3H, *H7*, *H2'*), 6.93 (br d, *J* = 9.0 Hz, 1H, N-*H*), 6.91 (ddd, *J* = 7.3, 6.7, 1.3 Hz, 1H, *H6*), 6.80 (nfod, J_{app} = 8.8 Hz, 2H, *H3'*), 6.76 (dt, *J* = 9.1, 1.1 Hz, 1H, NC*H*), 3.86 (s, 3H, CO_2CH_3), 3.77 (s, 3H, C4'OCH_3), 3.58 (s, 3H, CO_2CH_3'), and 2.07 (s, 3H, O=CCH_3).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 169.4, 168.3, 160.8, 158.8, 134.8, 132.5, 127.7, 127.2, 125.7, 123.2, 117.7, 115.7, 114.8, 113.7, 111.5, 55.4, 52.5, 51.8, 46.9, and 23.6.

IR (neat): 3367 (br), 3276 (br), 3002, 2951, 2911, 2837, 1733, 1689, 1511, 1384, 1246, 1216, and 1179 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H^+]: calcd for $C_{28}H_{27}N_2O_6^+$, 411.1551; found, 411.1549.

(±)-Dimethyl 1-((5*H*-Dibenzo[*b*,*f*]azepine-5-carboxamido)(4-methoxyphenyl)methyl)indolizine-2,3-dicarboxylate (104)



A solution of **91a** (30 mg, 0.14 mmol, 1 equiv), DMAD (41 mg, 0.29 mmol, 2 equiv), carbamazepine (68 mg, 0.29 mmol, 2 equiv), and DCE (1.5 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 70 °C for 18.5 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (2:1 → 1:1 hex:EtOAc) to afford **104** (52 mg, 62%) as an orange oil.

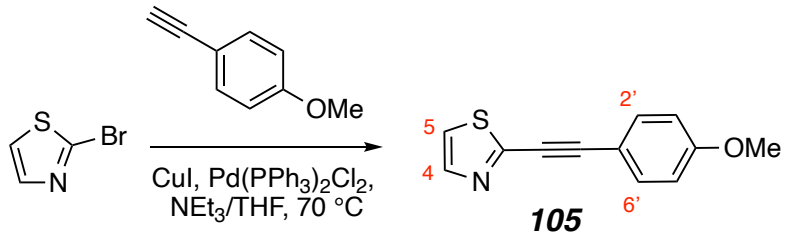
^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.32 (ddd, *J* = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 7.77 (ddd, *J* = 9.0, 1.2, 1.2 Hz, 1H, *H8*), 7.50 (dd, *J* = 7.9, 1.3 Hz, 1H), 7.47–7.39 (overlapping m, 4H), 7.36–7.29 (overlapping m, 3H), 7.04 (ddd, *J* = 9.1, 6.7, 1.2 Hz, 1H, *H7*), 6.95–6.89 (overlapping m, 4H), 6.85 (ddd, *J* = 7.2, 6.7, 1.3 Hz, 1H, *H6*), 6.73 (nfod, J_{app} = 8.9 Hz, 2H, *H3'*), 6.62 (dt, *J* = 9.3, 1.1 Hz, 1H, NC*H*ArAr'), 5.66 (d, *J* = 9.3, 1H, N*H*), 3.81 (s, 3H, CO_2CH_3), 3.73 (s, 3H, CO_2CH_3'), and 3.24 (s, 3H, C4''OCH_3).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 166.2, 161.0, 158.5, 156.2, 140.3, 140.0, 135.4, 135.3, 134.9, 133.4, 130.9, 130.0, 129.65, 129.64, 129.5, 129.3, 129.2, 127.8, 127.7, 127.3, 127.0, 125.5, 122.9, 118.1, 116.5, 114.6, 113.4, 111.6, 55.3, 51.9, 51.6, and 47.8.
(one of the arene carbons was not identified)

IR (neat): 3422, 3389, 3120, 3064, 3025, 3001, 2950, 2903, 2836, 2241, 1687, 1662, 1486, 1437, 1386, 1244, 1211, 1174, and 1098 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H^+]: calcd for $C_{35}H_{30}N_3O_6^+$, 588.2129; found, 588.2110.

2-((4-Methoxyphenyl)ethynyl)thiazole (105)



To a solution of 2-bromothiazole (0.25 mL, 2.8 mmol, 1 equiv) and 4-ethynylanisole (0.47 mL, 3.6 mmol, 1.3 equiv) in Et_3N (5 mL) and THF (5 mL) was added $Pd(PPh_3)_2Cl_2$ (39 mg, 0.056 mmol, 0.02 equiv) and CuI (21 mg, 0.11 mmol, 0.04 equiv). The reaction vessel was purged with N_2, and the suspension was stirred at 70 °C for 1 h. The crude mixture was passed through a silica plug (EtOAc elution) and concentrated under vacuum. The residue was purified by flash column chromatography (5:1 → 3:1 hex:EtOAc) to afford **105** (482 mg, 65%) as an orange oil.

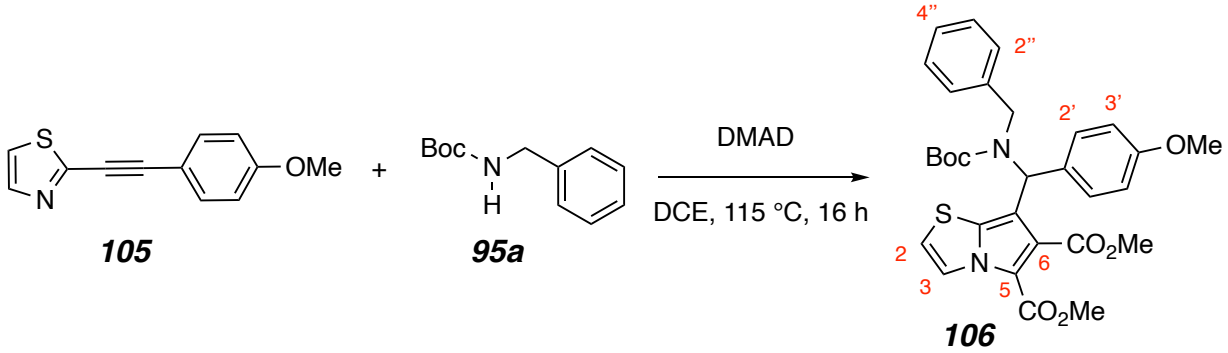
^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.84 (d, J = 3.3 Hz, 1H, *H4*), 7.53 (nfod, J_{app} = 8.9 Hz, 2H, *H2'*), 7.34 (d, J = 3.3 Hz, 1H, *H5*), 6.90 (nfod, J_{app} = 8.9 Hz, 2H, *H3'*), and 3.84 (s, 3H, OCH_3).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 160.7, 149.4, 143.6, 133.7, 120.4, 114.3, 113.6, 94.4, 81.4, and 55.5.

IR (neat): 3113, 3078, 3004, 2959, 2935, 2903, 2836, 2205, 1603, 1512, 1292, 1247, 1174, 1089 and 1027 cm^{-1}.

HRMS (ESI-TOF) *m/z* [$M+H^+$]: calcd for $C_{12}H_{10}NOS^+$, 216.0478; found, 216.0475.

(±)-Dimethyl 7-((Benzyl(*tert*-butoxycarbonyl)amino)(4-methoxyphenyl)methyl)pyrrolo[2,1-*b*]thiazole-5,6-dicarboxylate (106)



A solution of **105** (25 mg, 0.12 mmol, 1 equiv), DMAD (82 mg, 0.58 mmol, 5 equiv), *tert*-butyl benzylcarbamate (72 mg, 0.35 mmol, 3 equiv), and DCE (1 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 115 °C for 16 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (2.5:1 hex:EtOAc) to afford **106** (50 mg, 76%) as a clear colorless oil.

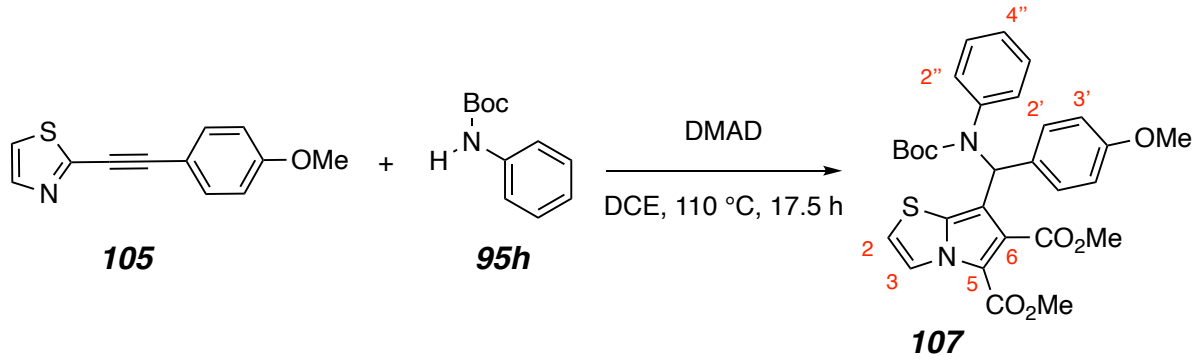
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.17 (d, J = 4.3 Hz, 1H, *H*3), 7.08 (nfod, J_{app} = 8.6 Hz, 2H, *H2'*), 7.03–6.97 (m, 3H, *H4"* & *H2"*), 6.82–6.79 (m, 4H, *H3"* & *H3'*), 6.75 (d, J = 4.3 Hz, 1H, *H*2), 6.70 (br s, 1H, NC*H*), 4.68 (br d, 1H, NCH_aH$_b$), 4.28 (d, J = 16.0 Hz, 1H, NCH$_a$$H_b$), 3.83 (s, 3H, CO_2CH_3), 3.79 (s, 3H, C4'OCH_3), 3.74 (s, 3H, CO_2CH_3'), and 1.41 [s, 9H, C(CH_3)$_3$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 165.2, 160.3, 159.1, 155.8, 138.9, 136.1, 130.4, 129.2, 127.6, 126.7, 126.5, 126.1, 122.3, 114.8, 114.0, 113.7, 113.5, 80.4, 55.5, 55.4, 52.3, 51.7, 48.9, and 28.4.

IR (neat): 3153, 3117, 3064, 3029, 3003, 2976, 2951, 2837, 1770, 1686, 1511, 1387, 1245, 1219, 1159, and 1103 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{30}H_{33}N_2O_7S^+$, 565.2003; found, 565.1985.

(±)-Dimethyl 7-(((*tert*-Butoxycarbonyl)(phenyl)amino)(4-methoxyphenyl)methyl)pyrrolo[2,1-*b*]thiazole-5,6-dicarboxylate (107)



105 ***95h*** ***107***

A solution of **105** (25 mg, 0.12 mmol, 1 equiv), DMAD (82 mg, 0.58 mmol, 5 equiv), *tert*-butyl phenylcarbamate (67 mg, 0.35 mmol, 3 equiv), and DCE (1 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 110 °C for 17.5 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (2:1 hex:EtOAc) to afford **107** (45 mg, 70%) as a yellow oil.

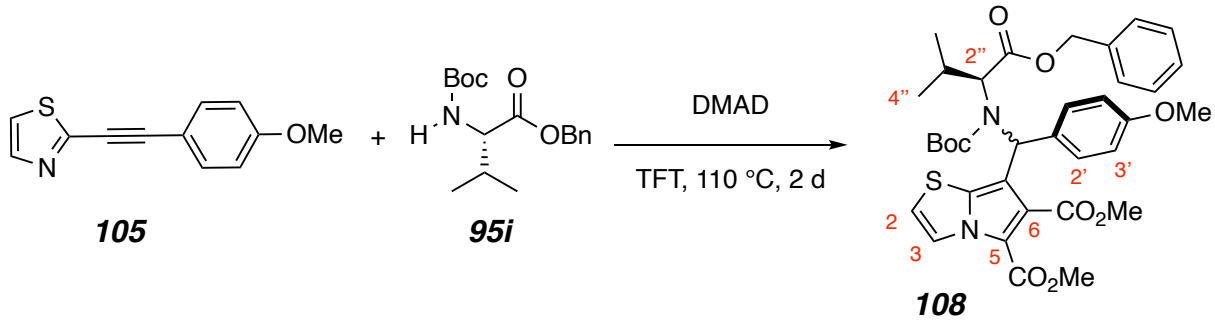
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.17 (d, J = 4.3 Hz, 1H, *H*3), 7.29 (nfod, J_{app} = 8.9 Hz, 2H, *H2'*), 7.09–6.99 (m, 5H, *H2", H3", H4"*), 6.89 (nfod, J_{app} = 8.8 Hz, 2H, *H3'*), 6.75 (s, 1H, NC*H*), 6.66 (d, J = 4.3 Hz, 1H, *H2*), 3.86 (s, 3H, CO_2CH_3), 3.84 (s, 3H, CO_2CH_3'), 3.82 (s, 3H, C4'OCH_3), and 1.35 [s, 9H, C(CH_3)$_3$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 165.6, 160.4, 159.1, 154.9, 141.1, 137.1, 130.8, 129.2, 128.7, 128.2, 126.9, 126.5, 121.9, 115.2, 114.0, 113.3, 112.9, 80.6, 58.4, 55.4, 52.5, 51.8, and 28.3.

IR (neat): 3152, 3116, 2976, 2952, 2838, 1730, 1691, 1510, 1382, 1246, 1219, 1164, and 1104 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{29}H_{31}N_2O_7S^+$, 551.1846; found, 551.1842.

(±)-Dimethyl 7-((*S*)-(((*S*)-1- and 7-((*S*)-(((*R*)-1-(Benzyloxy)-3-methyl-1-oxobutan-2-yl)(*tert*-butoxycarbonyl)amino)(4-methoxyphenyl)methyl)pyrrolo[2,1-*b*]thiazole-5,6-dicarboxylate (108)



105 ***95i*** ***108***

A solution of **105** (20 mg, 0.09 mmol, 1 equiv), DMAD (40 mg, 0.28 mmol, 3 equiv), benzyl (*tert*-butoxycarbonyl)-*L*-valinate[36] (57 mg, 0.19 mmol, 2 equiv), and TFT (1 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 110 °C for 2 d. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (2.5:1 hex:EtOAc) to afford a coeluting mixture of ***S,S*-108** and ***S,R*-108** (34 mg, 55%) as a clear oil. The ratio of isomers was ca. 1.1:1.0; the relative configurations of the major vs. minor isomers were not assigned.

Major diastereomer (extracted from the mixture of diastereomers):
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.31 (d, *J* = 4.3 Hz, 1H, *H*3), 7.36–7.29 (overlapping m, 5H, CO_2CH_2-C_6H_5), 7.12 (nfod, J_{app} = 8.6 Hz, 2H, *H2'*), 6.83 (d, *J* = 4.3 Hz, 1H, *H2*), 6.63 (nfod, J_{app} = 8.8 Hz, 2H, *H3'*), 6.26 (s, 1H, NC(PMP)*H*), 5.10 (d, *J* = 12.2 Hz, 1H, $CO_2CH_aH_b$), 5.06 (d, *J* = 12.2 Hz, 1H, $CO_2CH_aH_b$), 3.97 (d, *J* = 8.1 Hz, 1H, *H*2''), 3.87 (s, 3H, CO_2CH_3), 3.86 (s, 3H, CO_2CH_3'), 3.73 (s, 3H, C4'OCH_3), 2.28 (dqq, *J* = 8.1, 6.8, 6.8 Hz, 1H, *H*3''), 1.31 [s, 9H, $C(CH_3)_3$], 0.93 (d, *J* = 6.7 Hz, 3H, C3''$C_aH_3C_bH_3$), and 0.72 (d, *J* = 6.8 Hz, 3H, C3''$C_aH_3C_bH_3$).

Minor diastereomer (extracted from the mixture of diastereomers):
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.27 (d, *J* = 4.3 Hz, 1H, *H*3), 7.36–7.29 (overlapping m, 5H, CO_2CH_2-C_6H_5), 7.24 (nfod, J_{app} = 8.7 Hz, 2H, *H2'*), 6.79 (br d, *J* = 4.3 Hz, 1H, *H2*), 6.71 (nfod, J_{app} = 9.0 Hz, 2H, *H3'*), 6.09 (br s, 1H, NC(PMP)*H*), 5.06 (d, *J* = 12.1 Hz, 1H, $CO_2CH_aH_b$), 5.03 (d, *J* = 12.1 Hz, 1H, $CO_2CH_aH_b$), 3.94 (br d, *J* = 8.1 Hz, 1H, *H*2''), 3.82 (s, 3H, CO_2CH_3), 3.77 (br s, 3H, C4'OCH_3), 3.70 (br s, 3H, CO_2CH_3'), 2.28 (br dqq, *J* = 8.7, 6.7, 6.7 Hz, 1H, *H*3''), 1.25 [br s, 9H, $C(CH_3)_3$], 0.98 (d, *J* = 6.6 Hz, 3H, C3''$C_aH_3C_bH_3$), and 0.75 (d, *J* = 6.8 Hz, 3H, C3''$C_aH_3C_bH_3$).

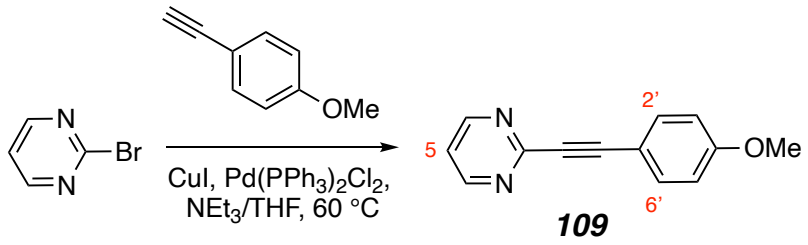
^{13}C NMR, IR, and HRMS data are of the mixture of diastereomers

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 171.0, 170.7, 165.8, 165.7, 160.43, 160.39, 158.8, 158.3, 154.9, 154.8, 137.0, 136.4, 135.78, 135.75, 132.2, 131.8, 129.7, 128.9, 128.7, 128.61, 128.56, 128.29, 128.27, 128.14, 127.4, 126.5, 122.4, 122.2, 115.9, 115.7, 114.3, 113.6, 113.51, 113.48, 112.6, 112.5, 81.01, 80.96, 66.8, 66.74, 66.73, 65.4, 56.4 (br, 2x), 55.31, 55.27, 52.5, 52.3, 51.84, 51.76, 29.9, 29.7, 28.3, 28.2, 20.3 (br, 2x), 19.79, and 19.76.

IR (neat): 3154, 3116, 3066, 2964, 2953, 2875, 2837, 1732, 1687, 1510, 1384, 1243, 1218, 1155, and 1107 cm^{-1}.

HRMS (ESI-TOF) *m/z* [$M+H^+$]: calcd for $C_{35}H_{41}N_2O_9S^+$, 665.2527; found, 665.2510.

2-((4-Methoxyphenyl)ethynyl)pyrimidine (109)



109

To a solution of 2-bromopyrimidine (167 mg, 1.1 mmol, 1 equiv) and 1-ethynyl-4-methoxybenzene (0.15 mL, 1.1 mmol, 1 equiv) in Et_3N (2 mL) and THF (2 mL) was added $Pd(PPh_3)_2Cl_2$ (15 mg, 0.02 mmol, 0.02 equiv) and CuI (8 mg, 0.04 mmol, 0.04 equiv). The reaction vessel was purged with N_2, and the suspension was stirred at 60 °C for 2 h. The crude mixture was passed through a silica plug (EtOAc elution) and concentrated under vacuum. The residue was purified by flash column chromatography (1.5:1 → 1:1 hex:EtOAc) to afford **109** (188 mg, 85%) as a white crystalline solid.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.74 (d, J = 4.9 Hz, 2H, *H4*), 7.62 (nfod, J_{app} = 8.9 Hz, 2H, *H2'*), 7.22 (t, J = 4.9 Hz, 1H, *H5*), 6.90 (nfod, J_{app} = 8.9 Hz, 2H, *H3'*), and 3.84 (s, 3H, C4'OC*H*$_3$).

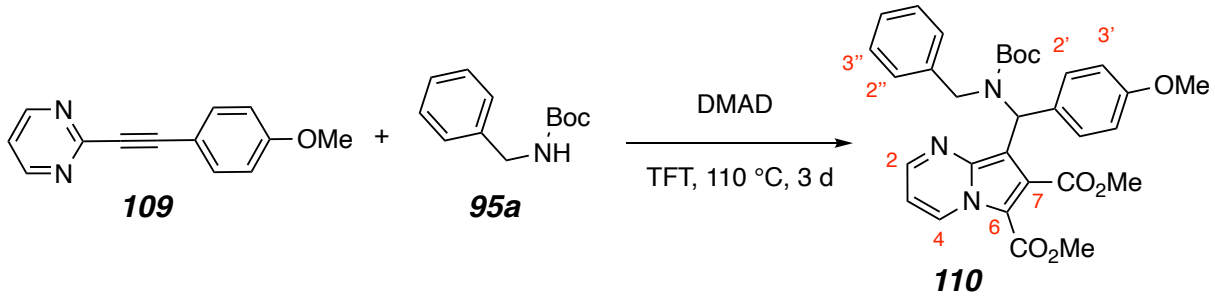
^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ 160.9, 157.4, 153.7, 134.5, 119.4, 114.3, 113.4, 88.8, 87.3, and 55.5.

IR (neat): 3120, 3038, 3005, 2960, 2935, 2838, 2225, 2193, 1605, 1561, 1511, 1412, 1253, and 1168 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{13}H_{10}ClN_2O^+$, 211.0866; found, 211.0862.

mp:147–149 °C.

(±)-Dimethyl 8-((Benzyl(*tert*-butoxycarbonyl)amino)(4-methoxyphenyl)methyl)pyrrolo[1,2-*a*]pyrimidine-6,7-dicarboxylate (110)



109 ***95a*** ***110***

A solution of **109** (20 mg, 0.1 mmol, 1 equiv), DMAD (68 mg, 0.5 mmol, 5 equiv), *tert*-butyl benzylcarbamate (39 mg, 0.2 mmol, 2 equiv), and TFT (1 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 110 °C for 3 d. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (1.5:1 hex:EtOAc) to afford **110** (29 mg, 54%) as a yellow oil.

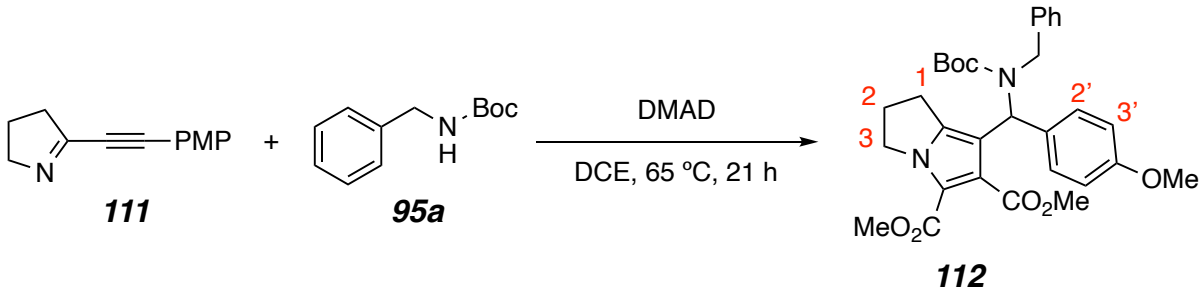
^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.24 (dd, J = 7.2, 1.8 Hz, 1H, *H4*), 8.25 (dd, J = 4.0, 1.8 Hz, 1H, *H2*), 7.15 (nfod, J_{app} = 8.4 Hz, 2H, *H2'*), 7.15–6.92 (br m, 1H, NC*H*), 6.82 (nfod, J_{app} = 8.7 Hz, 2H, *H3'*), 6.81–6.77 (br m, 3H, *H4"* & *H3"*), 6.75–6.72 (br m, 2H, *H2"*), 6.71 (dd, J = 7.2, 4.0 Hz, 1H, *H3*), 5.08–4.73 (br m, 1H, NCH_aH$_b$), 4.67–4.46 (br m, 1H, NCH$_a$$H_b$), 3.84 (s, 3H, C6$CO_2CH_3$), 3.79 (s, 3H, C4'O$CH_3$), 3.59 (br s, 3H, C7$CO_2CH_3$), and 1.43 [s, 9H, C($CH_3$)$_3$].

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 166.4 (C7CO_2CH_3), 160.6(C6CO_2CH_3), 158.6 (C4'OCH_3), 147.3, (*C2*) 141.3 (*C*8a), 139.3 (br, *C1"*), 133.5 (*C4*), 131.3 [*C1'*, HMBC only (too broad to discern in the 1D)], 129.8 (br), 128.7 (*C2'*), 126.9 (C3"), 125.9 (*C2"*), 125.4 (*C4"*), 113.6 (*C3'*), 112.3, 109.9 (*C3*), 107.4 (*C6*), 80.1 [O*C*(CH_3)$_3$], 55.4 (C4'OCH_3), 54.4 [v br, ArCH(N)], 52.5 (C7CO_2CH_3), 51.9 (C6CO_2CH_3), 48.1 (br, PhCH_2), and 28.5 [OC(CH_3)$_3$].
(the Boc carbonyl carbon resonance at ca. 158 ppm is so broad that it wasn't discerned).
HSQC, HMBC

IR (neat): 3062, 3030, 3000, 2975, 2952, 2837, 1735, 1686, 1511, 1402, 1242, 1176, and 1161 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+Na$^+$]: calcd for $C_{31}H_{33}N_3NaO_7^+$, 582.2211; found, 582.2192 (0.39%) and calcd for [M+H$^+$–BnNHBoc]: $C_{19}H_{17}N_2O_5^+$, 353.1132; found 353.1123 (100%).

(±)-Dimethyl 7-((Benzyl(tert-butoxycarbonyl)amino)(4-methoxyphenyl)methyl)-2,3-dihydro-1H-pyrrolizine-5,6-dicarboxylate (112)



The alkyne **111**[37] (23.5 mg, 1.0 equiv, 0.115 mmol) was dissolved in DCE in a screw-capped culture tube containing molecular sieves. *N*-Boc amine **95a** (70.0 mg, 0.337 mmol, 2.9 equiv) and DMAD (36.9 µL, 0.301 mmol, 2.6 equiv) were added. The reaction mixture was heated to 65 ºC for 21 hours. The crude mixture was filtered through silica gel and purified via MPLC (4:1 hex:EtOAc) to afford **112** as a clear oil (27.8 mg, 34%).

^{1}H NMR (500 MHz, CDCl3): δ 7.12–7.02 (m, 5H, Ph*H*), 6.94 (nfod, J_{app} = 7.7 Hz, 2H, *H2'*), 6.78 (nfod, J_{app} = 8.5 Hz, 2H, *H3'*), 6.50 (br s, 1H, NC*H*PMP), 4.75 (d, J = 16.6 Hz, 1H, NCH_aH$_b$), 4.36 (d, J = 16.3 Hz, NCH$_a$$H_b$), 4.01 (ddd, *J* = 12.1, 8.6, 6.1 Hz, 1H, C3H_aH$_b$), 3.98–3.90 (ddd, *J* = 11.9, 8.5, 6.1 Hz, 1H, C3H$_a$$H_b$), 3.777 (s, 3H, -CO$_2CH_3$), 3.775 (s, 3H, -CO$_2CH_3$'), 3.60 (s, 3H, ArOC$H_3$), 2.34–2.25 (br m, 1H, C1H_aH$_b$), 2.24–2.09 (m, 2H, C2H$_a$H$_b$), 2.08–1.98 (br m, 1H, C1H$_a$$H_b$), and 1.40 (s, 9H, -CO$_2$(C$H_3$)$_3$).

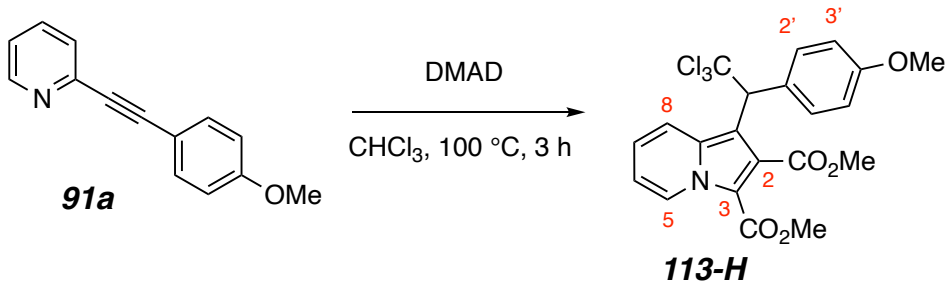
^{13}C{^{1}H} NMR (126 MHz, CDCl$_3$): δ 166.0, 160.7, 158.5, 156.1 (br), 141.8, 139.8, 128.5, 127.6 (2x), 126.8 (br), 126.2, 125.8, 116.6, 115.2, 113.6, 80.1, 55.8, 55.4, 52.0, 51.6, 48.4, 47.9, 28.5, 26.4, and 24.4.

(the broadened resonance at 126.8, as well as the methylene protons at C1, reflect an intermediate rate of rotation near the BocNCHPMP carbon.)

IR: 2951, 1686, 1610, 1246, 1217, and 1095 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H]: calcd for $C_{31}H_{37}N_2O_7^+$, 549.2595; found, 549.2567.

(±)-Dimethyl 1-(2,2,2-Trichloro-1-(4-methoxyphenyl)ethyl)indolizine-2,3-dicarboxylate (113-H)



A solution of 2-((4-methoxyphenyl)ethynyl)pyridine[31] (15 mg, 0.072 mmol, 1 equiv), DMAD (20 mg, 0.14 mmol, 2 equiv), and $CHCl_3$ (1 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 100 °C for 3 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (3:1 hex:EtOAc) to afford **113-H** (25 mg, 74%) as a clear colorless oil.

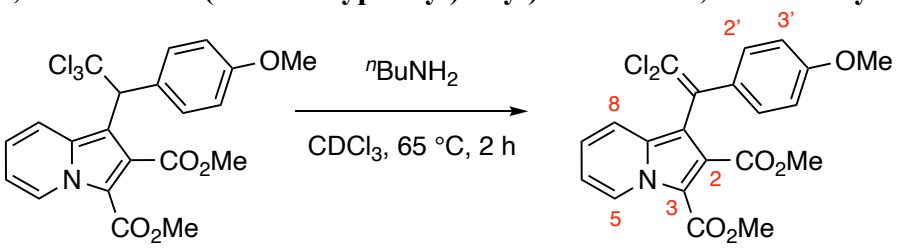
^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.39 (ddd, J = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 7.63 (nfod, J_{app} = 9.0 Hz, 2H, *H2'*), 7.52 (ddd, J = 9.2, 1.2, 1.2 Hz, 1H, *H8*), 6.93 (ddd, J = 9.2, 6.7, 1.2 Hz, 1H, *H7*), 6.85 (nfod, J_{app} = 9.0 Hz, 2H, *H3'*), 6.82 (ddd, J = 7.2, 6.7, 1.4 Hz, 1H, *H6*), 5.69 (dd, J = 0.8, 0.8 Hz, 1H, Cl_3CCH), 3.95 (s, 3H, CO_2CH_3), 3.90 (s, 3H, CO_2CH_3'), and 3.78 (s, 3H, C4'OCH_3).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 167.3, 161.0, 158.6, 135.1, 130.3, 129.7, 129.2, 127.4, 123.0, 120.0, 114.4, 113.6, 111.3, 101.9, 61.5, 55.3, 52.7, and 51.8. (one aromatic carbon atom resonance not identified in either the 1D ^{13}C or HMBC spectra)

IR (neat): 3119, 2999, 2952, 2908, 2837, 1693, 1532, 1378, 1215, and 1183 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{21}H_{18}Cl_3NO_5^+$, 470.0323; found, 470.0325.

Dimethyl 1-(2,2-Dichloro-1-(4-methoxyphenyl)vinyl)indolizine-2,3-dicarboxylate (114)



113-H ***114***

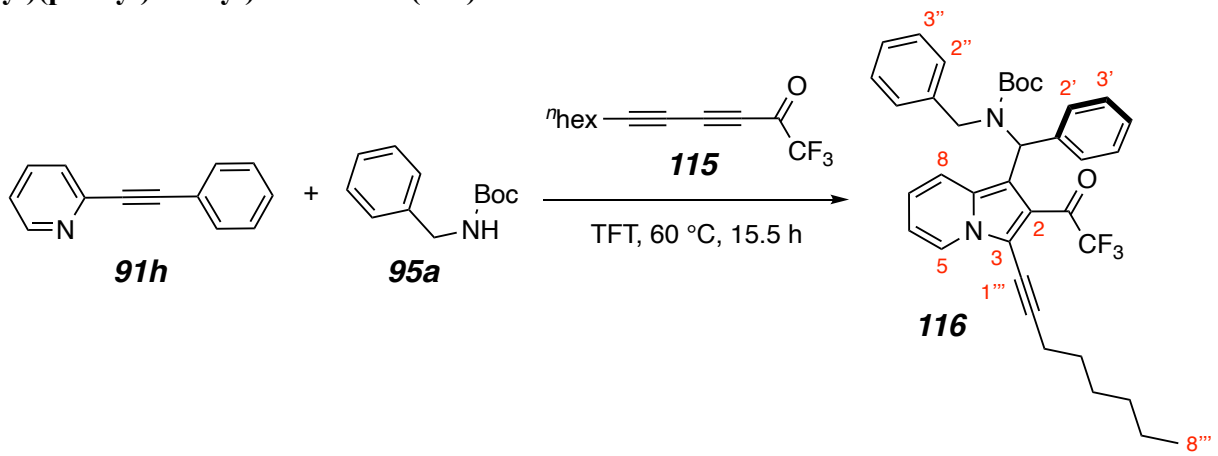
A solution of indolizine derivative **113-H** (36 mg, 0.068 mmol), $^{n}BuNH_2$ (1 mL), and $CDCl_3$ (1 mL) was charged in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 65 °C for 2 h. The crude mixture was cooled, concentrated under vacuum, passed through a silica pipette column (1:1.5 hex:EtOAc elution), and concentrated under vacuum to afford **114** (32 mg, 97%) as a clear colorless oil.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 9.41 (ddd, J = 7.2, 1.1, 1.1 Hz, 1H, *H5*), 7.41 (ddd, J = 9.0, 1.3, 1.3 Hz, 1H, *H8*), 7.28 (nfod, J_{app} = 8.9 Hz, 2H, *H2'*), 7.14 (ddd, J = 9.0, 6.7, 1.2 Hz, 1H, *H7*), 6.92 (ddd, J = 6.9, 6.9, 1.3 Hz, 1H, *H6*), 6.83 (nfod, J_{app} = 9.0 Hz, 2H, *H3'*), 3.86 (s, 3H, CO_2CH_3), 3.78 (s, 3H, C4'OCH_3), and 3.69 (s, 3H, CO_2CH_3').

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 165.8, 160.9, 159.5, 133.9, 131.6, 131.0, 130.7, 127.6, 127.2, 123.7, 102.1, 118.7, 114.6, 113.5, 113.3, 111.7, 55.4, 52.5, and 51.7.

IR (neat): 3119, 2998, 2850, 2909, 2837, 1731, 1689, 1606, 1499, 1438, 1381, 1209, 1175, and 1100 cm^{-1}.

tert-Butyl Benzyl((3-(oct-1-yn-1-yl)-2-(2,2,2-trifluoroacetyl)indolizin-1-yl)(phenyl)methyl)carbamate (116)



A solution of 2-(phenylethynyl)pyridine (15 mg, 0.08 mmol, 1 equiv), *tert*-butyl benzylcarbamate (35 mg, 0.17 mmol, 2 equiv), diyne **115** (29 mg, 0.13 mmol, 1.6 equiv), and TFT (1 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 60 °C for 15.5 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (6:1 hex:EtOAc) to afford **116** (28 mg, 54%) as an orange oil.

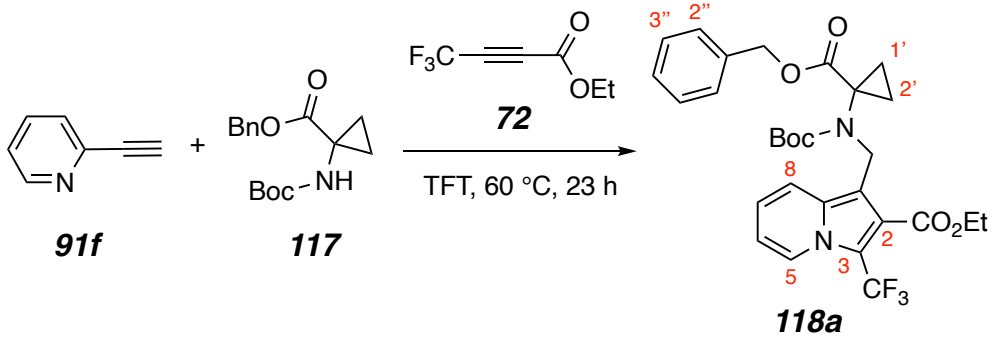
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.02–7.98 (nfom, 1H, *H5*), 7.33 (nfodd, J_{app} = 8.2, 7.7 Hz, 2H, *H3'*), 7.28 (s, 1H, NC*H*), 7.27 (tt, *J* = 6.8, 2.3 Hz, *H4'*), 7.20 (nfod, J_{app} = 8.2 Hz, 2H, *H2'*), 6.93 (tt, *J* = 7.4, 2.1 Hz, *H4"*), 6.85 (nfodd, J_{app} = 8.3, 7.7 Hz, 2H, *H3"*), 6.61–6.56 (m, 2H, *H6* & *H7*), 6.47 (br d, J = 7.5 Hz, 2H, *H2"*), 6.42–6.37 (br m, 1H, *H8*), 5.10 (br m, 1H, NCH_aH_b), 3.92 (br m, 1H, NCH_aH_b), 2.53 (t, *J* = 7.1 Hz, 2H, C3'''H_2), 1.64 (tt, *J* = 7.1, 7.1 Hz, 2H, C4'''H_2), 1.50–1.44 (nfom, 2H), 1.40–1.30 (m, 4H), and 0.92 (t, *J* = 7.1 Hz, 2H, C8'''H_3).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 178.5 (q, *J* = 37 Hz), 156.5 (br, NC=O), 141.1, 139.0, 132.3, 128.7, 127.4, 126.9, 126.6, 126.0, 125.8, 124.9 (*C5*), 121.0, 120.9 (*C2*), 119.6, 116.0 (CF_3, q, *J* = 290 Hz), 114.6, 113.5, 111.4 (*C3*), 103.6 (q, *J* = 2 Hz, *C2'"*), 80.4 (O*C*Me$_3$), 68.8 (q, *J* = 2 Hz, *C1'"*), 55.3, 48.4, 31.5, 28.7, 28.5, 28.4, 22.7, 20.0, and 14.2.

IR (neat): 3088, 3063, 3028, 2958, 2930, 2860, 1687, 1495, 1428, 1401, 1239, 1196, 1158, and 1021 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{37}H_{40}F_3N_2O_3^+$, 617.2986; found, 617.2963.

Ethyl 1-(((1-((Benzyloxy)carbonyl)cyclopropyl)(*tert*-butoxycarbonyl)amino)methyl)-3-(trifluoromethyl)indolizine-2-carboxylate (118a)



A solution of 2-ethynylpyridine (15 mg, 0.15 mmol, 1 equiv), ethyl 4,4,4-trifluorobut-2-ynoate (48 mg, 0.29 mmol, 2 equiv), the *N*-Boc derivative **117** (85 mg, 0.29 mmol, 2 equiv), and TFT (1 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 60 °C for 23 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (5:1 hex:EtOAc) to afford **118a** (27 mg, 33%) as a yellow oil.

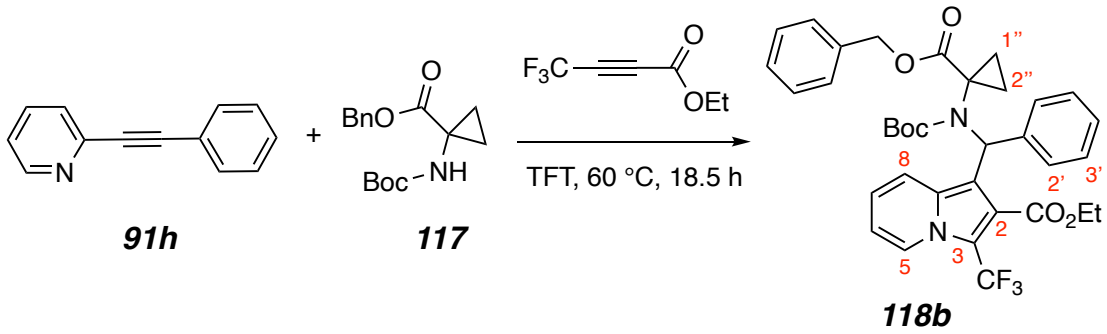
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.02 (br d, *J* = 7.1 Hz, 1H, *H5*), 7.99 (br d, *J* = 8.9 Hz, 1H, *H8*), 7.24–7.17 (br m, 3H, *H2"* & *H4"*), 7.02–6.97 (br m, 2H, *H3"*), 6.90 (br dd, *J* = 7.6, 7.6 Hz, 1H, *H7*), 6.71 (br ddd, *J* = 7.0, 6.7, 1.4 Hz, 1H, *H6*), 5.03 (br d, *J* = 15 Hz, NCH_aH_b), 5.02 (br d, *J* = 12 Hz, OCH_aH_b), 4.67 (d, *J* = 15.6 Hz, 1H, NCH_aH_b), 4.50 (d, *J* = 12.3 Hz, 1H, OCH_aH_b), 4.44–4.35 (br m, 1H, $CO_2CH_aH_b$), 4.30 (br m, 1H, $CO_2CH_aH_b$), 1.48–1.38 (br m, 2H, C1'H_aH_b & C2'H_aH_b), 1.35 (t, *J* = 7.2 Hz, 3H, $CO_2CH_2CH_3$), 1.33 (s, 9H, [s, 9H, $OC(CH_3)_3$], and 1.20–1.10 (br m, 2H, C1'H_aH_b & C2'H_aH_b).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 172.8, 164.9, 156.7, 135.7, 134.2, 128.4, 128.0, 127.7, 124.2, 122.7, 121.7 (CF_3, q, *J* = 268 Hz), 120.33, 120.26, 114.2, 110.9, 109.3 (q, *J* = 40 Hz), 80.2, 66.7, 61.7, 40.0, 39.7, 28.3, 22.7, 18.3, and 14.1.

IR (neat): 2978, 2935, 1723, 1694, 1391, 1365, 1297, 1247, 1210, 1151, and 1092 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{29}H_{32}F_3N_2O_6^+$, 561.2207; found, 561.2188.

(±)-Ethyl 1-(((1-((Benzyloxy)carbonyl)cyclopropyl)(*tert*-butoxycarbonyl)amino)(phenyl)methyl)-3-(trifluoromethyl)indolizine-2-carboxylate (118b)



91h ***117*** ***118b***

A solution of **91h** (20 mg, 0.11 mmol, 1 equiv), ethyl 4,4,4-trifluorobut-2-ynoate (37 mg, 0.22 mmol, 2 equiv), the *N*-Boc derivative **117** (65 mg, 0.22 mmol, 2 equiv), and TFT (1 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 60 °C for 18.5 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (5:1 hex:EtOAc) to afford **118b** (46 mg, 65%) as a yellow oil.

*A pair of Boc-broadened, diastereomeric rotamers in a nearly 1:1 ratio. The assignment of structure to this compound relies on inferences drawn from the NMR spectra of the simpler cyclopropane derivative **118a**, which lacks a stereogenic carbon atom.*

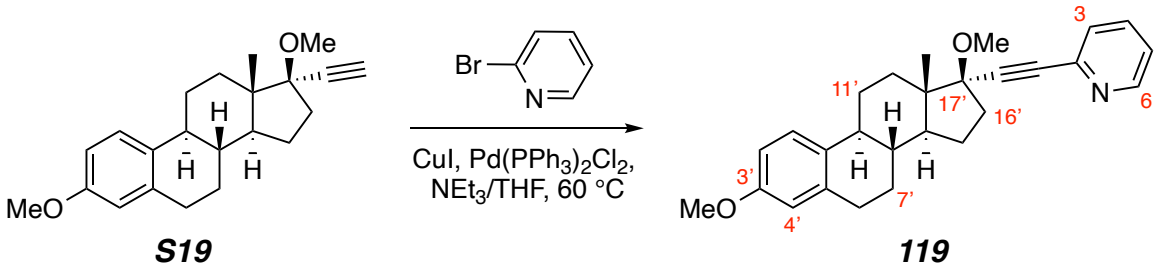
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.14 (br m, $J_{W1/2}$ = 16 Hz, 1H, $H5_{rot1}$), 8.01 (br m, $J_{W1/2}$ = 17 Hz, H, $H5_{rot2}$), 7.5–6.9 (series of br m's, 23H), 6.8–6.65 (br m, 4H), 6.49 (br s, 1H, PhC*H*N), 5.18–5.01 (two br s's, PhCH_aH$_b$, rot1 and rot2), 4.85–4.75 (br s, PhCH$_a$$H_b$$_{rot1}$), 4.73–4.56 (br s, PhCH$_a$$H_b$$_{rot2}$), 4.30–4.05 (br m, 4H, CO_2CH_2Me), 1.75–1.61 (br m, 1H, cyprop), 1.6–1.4 (br m, 3H, cyprop's), and 1.37–1.14, 27H, cyprop's, t-Bu's, CH_2CH_3's).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 173.2 (br), 172.5 (br), 165.3 (br), 164.2 (br), 156.1 (br), 155.5 (br), 136.1 (br), 135.6 (br), 133.2 (br), 132.7 (br), 128.3 (br), 128.2 (br), 127.9 (br), 127.7 (br), 127.3 (br), 126.9 (br), 126.7 (br), 124.5 (br), 123.9 (br), 122.7 (br), 120.6–120.0 (overlapping br m's), 119.3 (br), 113.6, 80.4 (br), 80.1 (br), 66.6 (br), 66.3 (br), 61.6, 59.3 (br, PhCHN$_{rot1}$), 56.5 (v br, (PhCHN$_{rot2}$), 39.3 (v br), 28.0, 19.3 (br), 18.1 (v br), and 13.8. HSQC

IR (neat): 3089, 3064, 3031, 2978, 2933, 1709, 1394, 1326, 1298, 1249, 1208, 1153, and 1092 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{35}H_{36}F_3N_2O_6^+$, 637.2520; found, 637.2501.

2-(((8*R*,9*S*,13*S*,14*S*,17*S*)-3,17-Dimethoxy-13-methyl-7,8,9,11,12,13,14,15,16,17-decahydro-6*H*-cyclopenta[*a*]phenanthren-17-yl)ethynyl)pyridine (119)



S19 ***119***

To a solution of 2-bromopyridine (70 µL, 0.73 mmol, 1 equiv) and methylated ethinyl estradiol[38] **S19** (250 mg, 0.77 mmol, 1.1 equiv) in Et_3N (1 mL) and THF (2 mL) was added $Pd(PPh_3)_2Cl_2$ (10 mg, 0.014 mmol, 0.02 equiv) and CuI (6 mg, 0.032 mmol, 0.04 equiv). The reaction vessel was purged with N_2, and the suspension was stirred at 60 °C for 5 h. The crude mixture was passed through a silica plug (EtOAc elution) and concentrated under vacuum. The residue was purified using MPLC (3:1→ 2:1 hex:EtOAc) to afford **119** (170 mg, 55%) as a white crystalline solid.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.60 (ddd, *J* = 4.9, 1.8, 1.0 Hz, 1H, *H6*), 7.65 (ddd, *J* = 7.7, 7.7, 1.8 Hz, 1H, *H4*), 7.47 (ddd, *J* = 7.8, 1.1, 1.1 Hz, 1H, *H3*), 7.23 (ddd, *J* = 7.6, 4.9, 1.2 Hz, 1H, *H5*), 7.20 (dd, *J* = 8.7, 1.2 Hz, 1H, *H1'*), 6.70 (dddd, *J* = 8.6, 2.9, 0.8, 0.8 Hz, 1H, *H2'*), 6.62 (ddd, *J* = 2.9, 1.0, 1.0 Hz, 1H, *H4'*), 3.77 (s, 3H, C3'OC*H*$_3$), 3.51 (s, 3H, C17'OC*H*$_3$), 2.86 (dddddd, *J* = 17.2, 11.1, 6.2, 1.3, 1.3, 0.8 Hz, 1H, C6'H_aH_b), 2.83 (br ddd, *J* = 17.0, 7.0, 3.2 Hz, 1H, C6'H$_a$*H$_b$*), 2.41 (ddd, *J* = 13.8, 9.3, 5.7 Hz, 1H, C16'H_aH_b), 2.35 (dddd, *J* = 13.4, 4.3, 4.3, 3.8 Hz, 1H, C11'H_aH_b), 2.26 (br ddd, *J* = 11.4, 11.4, 4.3 Hz 1H, *H9'*), 2.10 (dddd, *J* = 13.1, 13.1, 4.3, 0.9 Hz, 1H, C12'H_aH_b), 2.08 (ddd, *J* = 13.7, 12.1, 3.4 Hz, 1H, C16'H$_a$*H$_b$*), 1.92–1.82 (m, 4H, C7'H_aH_b, C12'H$_a$*H$_b$*, *H14'*, C15'H_aH_b), 1.52 (dddd, *J* = 13.3, 13.3, 12.0, 4.1 Hz, 1H, C11'H$_a$*H$_b$*), 1.53–1.33 (m, 3H, C7'H$_a$*H$_b$*, *H8'*, C15'H$_a$*H$_b$*), and 0.93 (d, *J* = 0.8 Hz, 3H, C13'*CH*$_3$).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 157.5 (*C3'*), 150.2 (*C6*), 143.5, 138.1, 136.2, 132.8, 127.6, 126.5, 122.9, 113.9, 111.6, 90.7, 87.5, 86.3 (*C17'*), 55.3 (C3'OCH$_3$), 53.8 (C17'OCH$_3$), 50.0 (*C14'*), 48.2 (*C13'*), 43.6 (*C9'*), 39.4 (*C8'*), 36.7 (*C16'*), 34.6 (*C12'*), 30.0 (*C6'*), 27.3 (*C7'*), 26.7 (*C11'*), 23.1 (C15'), and 13.0 (C13'*C*H$_3$).
HSQC
HMBC

IR (neat): 3050, 2931, 2871, 2828, 2227, 1610, 1581, 1499, 1463, 1426, 1277, 1255, 1238, 1095, and 1041 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{27}H_{32}NO_2^+$, 402.2428; found, 402.2419.

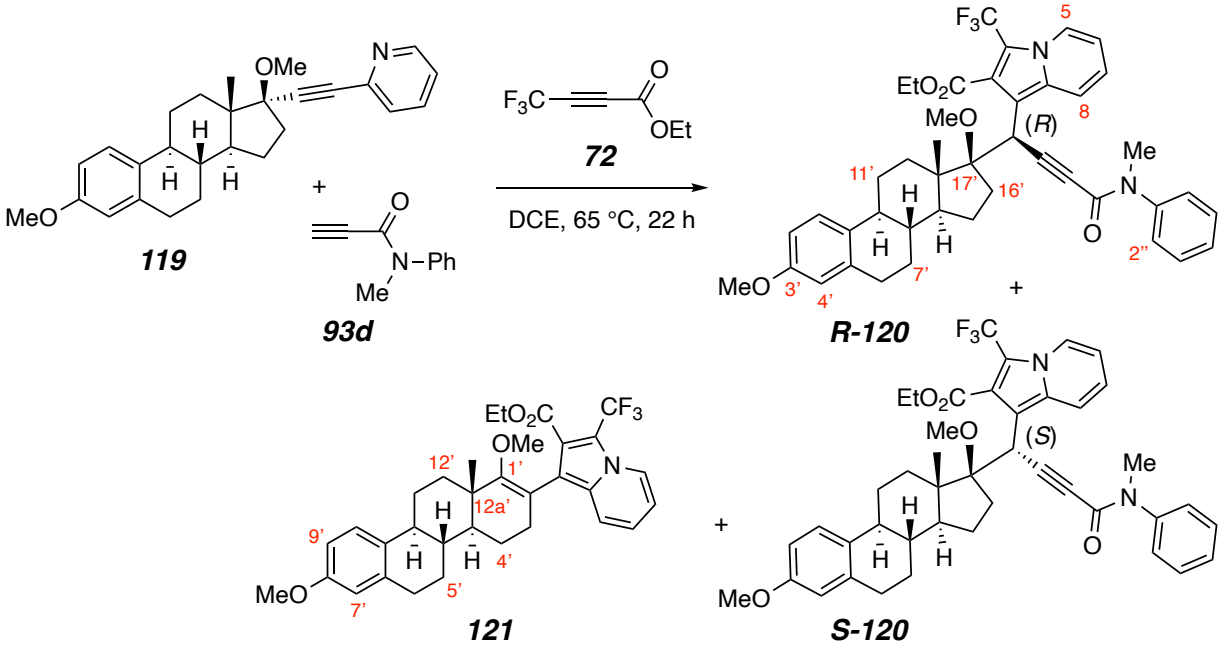
mp: 152–154 °C.

Ethyl 1-((*R*)-1-((8*R*,9*S*,13*S*,14*S*,17*R*)-3,17-Dimethoxy-13-methyl-7,8,9,11,12,13,14,15,16,17-decahydro-6*H*-cyclopenta[*a*]phenanthren-17-yl)-4-(methyl(phenyl)amino)-4-oxobut-2-yn-1-yl)-3-(trifluoromethyl)indolizine-2-carboxylate (120-R)

Ethyl 1-((*S*)-1-((8*R*,9*S*,13*S*,14*S*,17*R*)-3,17-Dimethoxy-13-methyl-7,8,9,11,12,13,14,15,16,17-decahydro-6*H*-cyclopenta[*a*]phenanthren-17-yl)-4-(methyl(phenyl)amino)-4-oxobut-2-yn-1-yl)-3-(trifluoromethyl)indolizine-2-carboxylate (120-S)

and

Ethyl 1-((4a*S*,4b*R*,10b*S*,12a*S*)-1,8-Dimethoxy-12a-methyl-3,4,4a,4b,5,6,10b,11,12,12a-decahydrochrysen-2-yl)-3-(trifluoromethyl)indolizine-2-carboxylate (121)



A solution of alkynyl pyridine **119** (40 mg, 0.10 mmol, 1 equiv), *N*-methyl-*N*-phenylpropiolamide (48 mg, 0.30 mmol, 3 equiv), ethyl 4,4,4-trifluorobut-2-ynoate (33 mg, 0.20 mmol, 2 equiv), and DCE (1.5 mL) was charged with molecular sieves in a threaded culture tube, sealed with a Teflon-lined screw cap, and heated at 65 °C for 22 h. The crude mixture was passed through a silica plug (EtOAc elution) and then concentrated under vacuum. The residue was purified using MPLC (3:1 hex:EtOAc) to afford i) a faster eluting, less pure component, which was further purified using MPLC (8:1 hex:EtOAc) to afford **121** (5 mg, 9%) as a clear colorless oil and ii) a slower eluting mixture (10:1) of **R-120** and **S-120** (35 mg, 48%,) as a yellow oil.

Data for 120 the coeluting pair of epimers at the propargylic stereogenic carbon atom

major epimer (*R*-120)*:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.10 (br d, *J* = 7.2 Hz, 1H, *H5*), 7.86 (br d, *J* = 9.3 Hz, 1H, *H8*), 7.23–7.16 (m, 6H, C_6H_5 & *H1'*), 6.88 (ddd, *J* = 9.4, 6.6, 1.1 Hz, 1H, *H7*), 6.73 (dd, *J* = 8.4, 2.5

Hz, 1H, *H2'*), 6.72 (ddd, *J* = 7.3, 6.7, 1.4 Hz, 1H, *H6*), 6.64 (ddd, *J* = 2.8, 1.0, 1.0 Hz, 1H, *H4'*), 4.75 (s, 1H, C≡C-C*H*), 4.37 (dq, *J* = 10.7, 7.1 Hz, 1H, $CO_2CH_aH_b$), 4.31 (dq, *J* = 10.7, 7.1 Hz, 1H, $CO_2CH_aH_b$), 3.79 (s, 3H, C3'OCH_3), 3.27 (s, 3H, NCH_3), 2.91–2.83 (m, 2H, C6'CH_2), 2.66 (s, 3H, C17'OCH_3), 2.19 (br m, 1H, C11'H_aH_b), 2.14–2.00 (m, 2H, *H9'*, *H14'*), 2.00–1.85 [m, 3H, C16'H_aH_b, C16'H_aH_b (HMBC with the methine carbon), C7'H_aH_b], 1.80 (br m, 1H, C15'H_aH_b), 1.53 (br m, 2H, C12'H_aH_b, C12'H_aH_b), 1.50–1.30 (m, 4H, C7'H_aH_b, *H8'*, C11'H_aH_b, C15'H_aH_b), 1.36 (t, *J* = 7.2 Hz, 3H, $CO_2CH_2CH_3$), and 0.75 (s, 3H, C13'CH_3).

^{13}C{^{1}H} NMR (126 MHz, $CDCl_3$): δ 164.8 (O*C*=O), 157.5 (*C3'*), 153.9 (N*C*=*O*), 142.9 (*C1"*), 138.1, 132.9, 132.6, 129.1 (*C3"*), 127.7, 127.2, 126.4, 124.5 (q, *J* = 4 Hz, *C5*), 123.8, 121.7 (q, *J* = 268 Hz, *C*F_3), 120.7 (*C8*), 120.2 (*C7*), 113.9, 113.4 (*C4'*), 111.6, 110.1 (q, *J* = 39 Hz, *C*3), 109.5 (*C1*), 93.9 (O=CC≡*C*), 91.7 (*C17'*), 78.6 (O=C*C*≡C), 61.4 (O*C*H_2), 55.3, 54.6, 50.6 (*C13'*), 48.9 (*C14'*), 43.4 (*C9'*), 39.6 (*C8'*), 36.5, 35.1 (C≡C-*C*H), 31.9 (*C12'*), 30.1 (*C6'*), 28.1, 26.9 (*C16'*), 26.5, 24.7 (*C15'*), 15.1 (C13'*C*H_3), and 14.1 (OCH_2CH_3).
HSQC
HMBC

minor epimer (*S*-120)*:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.24 (br m, 1H, *H8*), 8.15 (br m, 1H, *H5*), 7.35 (br m, 2H, *H3"*), 7.00 (br m, 1H, *H7*), 5.08 (s, 1H, C≡C-C*H*), 3.77 (s, 3H, C3'OCH_3), 3.49 (s, 3H, NCH_3), 2.73 (s, 3H, C17'OCH_3), 2.48 (br m, 1H, *H14'*), 2.39 (br m, 1H, *H16'*H_aH_b), 2.31 (br m, 1H, *H9'*), and 0.87 (s, 3H, C13'*C*H_3).

for the mixture of epimers:

IR (neat): 3062, 2980, 2933, 2873, 2833, 2219, 1724, 1635, 1498, 1373, 1254, 1208, 1154, and 1100 cm^{-1}.

HRMS (ESI-TOF) *m/z* [M+H$^+$]: calcd for $C_{43}H_{46}F_3N_2O_5^+$, 727.3352; found, 727.3341.

* A DP4+ analysis was performed, leading to the assignment of configuration for the major and minor epimers. See section II. of this SI (Chapter 4).

Data for 121:

^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.14 (br d, *J* = 7.2 Hz, 1H, *H5*), 7.34 (ddd, *J* = 9.1, 1.3, 1.3 Hz, 1H, *H8*), 7.25 (br m, 1H, *H10'*), 6.91 (br dd, *J* = 9.1, 6.6 Hz, 1H, *H7*), 6.76 (ddd, *J* = 7.1, 6.6, 1.4 Hz, 1H, *H6*), 6.74 (dd, *J* = 8.5, 2.9 Hz, 1H, *H9'*), 6.65 (d, *J* = 2.8 Hz, 1H, *H7'*), 4.45–4.37 (m, 1H, $CO_2CH_aH_b$), 4.37–4.30 (m, 1H, $CO_2CH_aH_b$), 3.79 (s, 3H, C8'OCH_3), 3.14 and 3.13 (br s, ca. 2H and 1H, rotamers for C1'OCH_3), 2.92–2.86 (m, 2H, C6'CH_2), 2.49–2.09 (m, 6H), 1.94 (br dd, *J* = 11.6, 6.2 Hz, 1H, C12'H_aH_b), 1.6–1.2 (m, 6H), 1.38 (t, *J* = 7.2 Hz, 3H, $CO_2CH_2CH_3$), 1.18 & 1.13 (br s, ca. 1H and 2H, rotamers for C12a'CH_3). [two sets of resonances (ca. 2.5:1 ratio) were detected for the OC$H_2$$CH_3$, C1'OC$H_3$, and C12a'C$H_3$ resonances, indicating the presence of a pair of atropisomers]

$^{13}C\{^{1}H\}$ NMR (126 MHz, $CDCl_3$): δ 162.8 (C1'), 157.7 (*C*8'), 138.1 (*C6a'*), 133.2 (*C10a'*), 131.4 (*C9*), 128.5, 126.4 (*C*10'), 124.4 (br, *C5*), 121.9 (q, *J* = 267 Hz, *C*F_3), 120.3 (*C7*), 119.8 (*C*8), 115.5 (br), 114.7 (br), 114.0 (*C6*), 113.5 (*C7'*), 111.7 (*C*9'), 92.8 (*C2'*), 61.5 (OCH_2CH_3), 61.2 (C1'O*C*H_3), 55.4 (C8'O*C*H_3), 48.6 (*C*4a'), 43.6 (*C*10b'), 40.1 (*C12a'*), 38.1 (*C*4b'), 35.2 (*C3'* or *C4'* HMBC from C12a'Me), 31.6 (*C3'* or *C4'* HMBC from C12a'Me), 30.3 (*C6'*), 26.7 (*C11'*), 26.3 (*C5'*), 20.8 (*C12'*), 18.2 (C12a'*C*H_3), and 14.2 (OCH_2CH_3). (the ester, which is located near to the atropisomeric center, carbonyl resonance was not observed)
HSQC
HMBC

IR (neat): 2929, 2867, 2836, 1731, 1502, 1254, 1212, 1153, and 1099 cm^{-1}.

HRMS (ESI-TOF) *m/z* [$M+H^+$]: calcd for $C_{33}H_{37}F_3NO_4^+$, 568.2669; found, 568.2659.

II. DP4+ Analysis of R- and S-120

The two possible propargylic epimers of **120** were subjected to a DP4+ analysis.[39] Each of the S- and R-configured epimers at the propargylic carbon was first subjected to a Monte Carlo conformational search in MacroModel (using Maestro) with the OPLS_2005 molecular mechanics (MM) force field within the Schrodinger software suite (Release 2020-4).[9] Both conformational search outputs revealed over 200 conformations for each diastereomer, but only the conformations found more than four times were selected for further optimization in Gaussian 16.[8] Each of these MM conformers was then used as the starting geometry for optimization in Gaussian "using the Sarotti-recommended functional (B3LYP) and basis set 6-31G(d) with no solvation (i.e., gas phase).[39] (A protocol outlining this process and the Python scripts used to streamline the dataflow are available in the literature.[10]) The NMR shielding tensors of all of the protons and carbons in each of the resulting unique conformers were calculated using the Sarotti recommended functional (mPW1PW91) and basis set [6-31+G(d,p)] with chloroform solvation modeling (IEFPCM). Boltzmann weighting was then used to compute the averaged chemical shift for each proton and carbon. These were used in the final DP4+ (spreadsheet) analysis; the following website provides clear instructions for how to proceed with that analysis: https://sarotti-nmr.weebly.com [accessed March 10, 2025]. The results are summarized below. For each of the topological isomers, only the **experimental** chemical shifts that could be definitively assigned were included for the proton and carbon resonances that were then used in the DP4+ comparisons with the computed candidate structures."[40] The analysis indicated that the major isolated epimer has the R configuration.

Functional		Solvent?		Basis Set		Type of Data	
mPW1PW91		PCM		6-31+G(d,p)		Shielding Tensors	
		DP4+	96.25%	3.75%	-	-	-
Nuclei	sp2?	Experimental	Isomer 1	Isomer 2	Isomer 3	Isomer 4	Isomer 5
H	x	8.1	22.9	22.9			
H	x	7.86	23.7	22.7			
H	x	6.88	24.1	24.1			
H	x	6.73	24.6	24.6			
H	x	6.72	24.3	24.3			
H	x	6.64	24.8	24.8			
H		4.75	26.9	26.8			
H		3.79	27.8	27.8			
H		3.27	28.3	28.2			
H		2.66	28.9	28.4			
H		1.36	30.2	30.2			
H		0.75	30.68	30.75			
C	x	164.8	30.42	31.97			
C	x	157.5	42.12	41.86			
C	x	153.9	46.26	45.32			
C	x	120.7	79.52	74.48			
C	x	120.2	76.78	76.73			
C	x	113.4	88.34	87.38			
C		35.1	157.50	156.47			

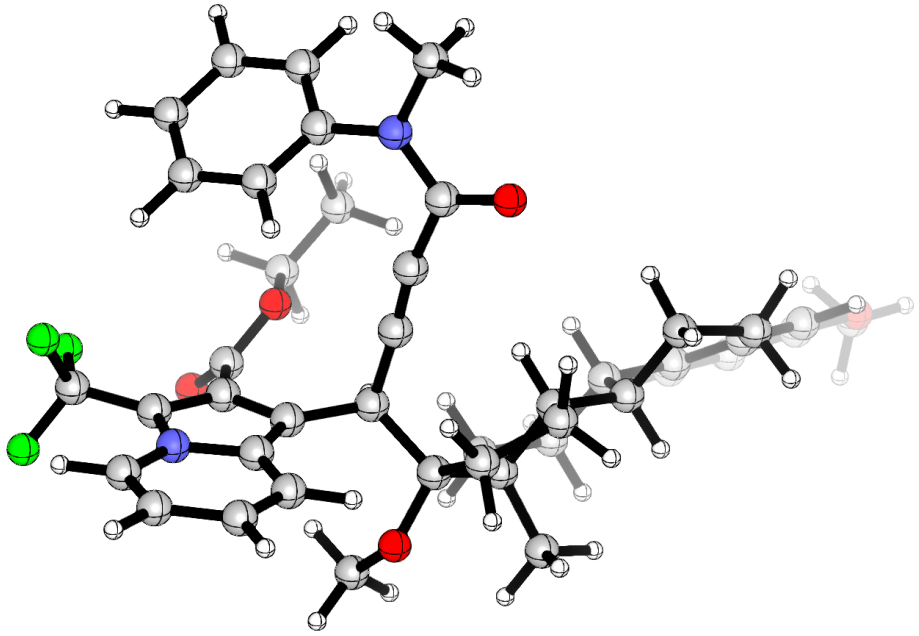
Figure S4. Screenshot of spreadsheet for the DP4+ analysis for the major diastereomer (**R-120**).

Functional		Solvent?		Basis Set		Type of Data	
mPW1PW91		PCM		6-31+G(d,p)		Shielding Tensors	
		DP4+	0.16%	99.84%	-	-	-
Nuclei	sp2?	Experimental	Isomer 1	Isomer 2	Isomer 3	Isomer 4	Isomer 5
H	x	8.24	23.7	22.7			
H	x	8.15	22.9	22.9			
H	x	7	24.1	24.1			
H	x	6.76	24.3	24.3			
H		5.08	26.9	26.8			
H		3.77	27.8	27.8			
H		3.49	28.3	28.2			
H		2.73	28.9	28.4			
H		0.87	30.7	30.8			

Figure S5. Screenshot of spreadsheet for the DP4+ analysis for the minor diastereomer (**S-120**).

Given on the following pages are the Gibbs energy values (in Hartree atomic units) and the Cartesian coordinates for each of the computed structures. A 3D representation (generated in CYLview20) for each of the structures is also shown.

Free Energy and Geometry for R-120 (Conformer 1 of 4):



Sum of electronic and thermal free energies: -2450.027451 a.u.

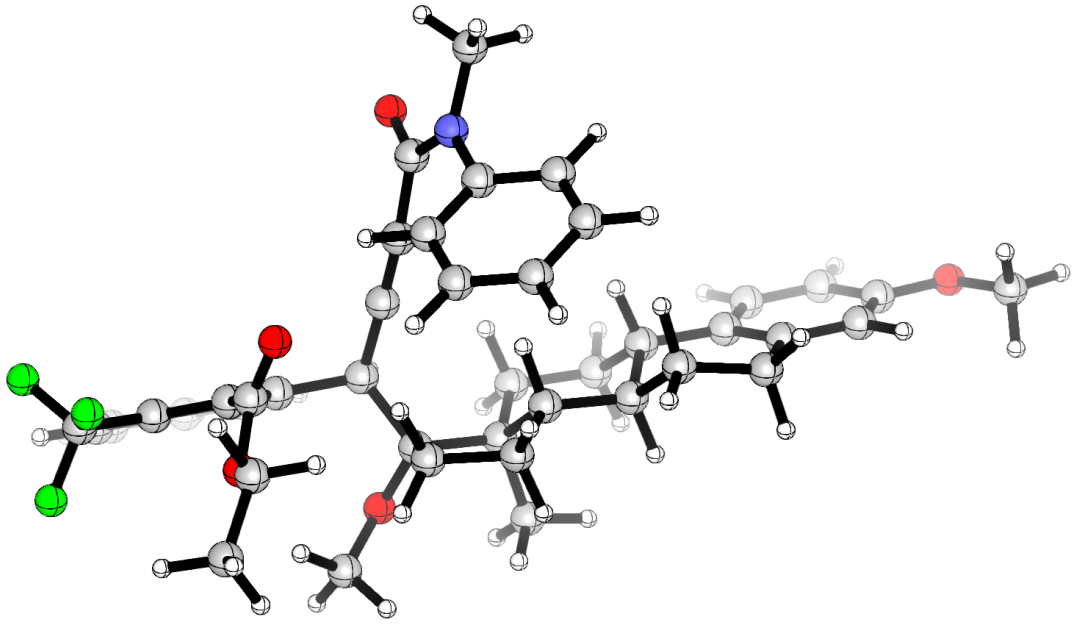
Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-6.093848	-0.358816	1.750232
2	6	0	-7.442253	-0.072602	1.972179
3	6	0	-8.229244	0.361557	0.902214
4	6	0	-7.645167	0.498644	-0.360281
5	6	0	-6.298179	0.209023	-0.579133
6	6	0	-5.490809	-0.234666	0.493320
7	8	0	-9.558298	0.676056	0.984167
8	6	0	-10.193781	0.557333	2.245068
9	6	0	-5.749744	0.355367	-1.988860
10	6	0	-4.219416	0.350043	-2.056905
11	6	0	-3.655997	-0.784746	-1.192278
12	6	0	-3.997444	-0.507147	0.294324
13	6	0	-2.140121	-0.965234	-1.333306
14	6	0	-1.565496	-2.123914	-0.472065
15	6	0	-1.910774	-1.836184	1.005786
16	6	0	-3.424503	-1.605671	1.216675
17	6	0	-0.042772	-2.122233	-0.939560
18	6	0	-0.190034	-1.908232	-2.480708
19	6	0	-1.546110	-1.194489	-2.736734
20	1	0	-3.460398	0.423515	0.552734

21	1	0	-4.163406	-1.712119	-1.499383
22	1	0	-1.692965	-0.037653	-0.949235
23	6	0	-2.176598	-3.489405	-0.881229
24	8	0	0.619506	-3.374966	-0.775114
25	6	0	0.801911	-3.885975	0.538549
26	6	0	0.832564	-0.961825	-0.266475
27	6	0	0.741351	0.315290	-0.984690
28	6	0	2.319012	-1.229422	-0.021322
29	6	0	3.290568	-1.773831	-0.879459
30	7	0	4.540683	-1.667057	-0.233257
31	6	0	4.359676	-1.093855	1.007193
32	6	0	3.000295	-0.816845	1.152779
33	6	0	3.271640	-2.381382	-2.161180
34	6	0	4.434881	-2.805167	-2.749428
35	6	0	5.675207	-2.654673	-2.067865
36	6	0	5.711175	-2.098696	-0.825223
37	6	0	5.531088	-0.710152	1.834985
38	6	0	2.380479	-0.284470	2.402573
39	8	0	2.563980	-0.746686	3.508422
40	8	0	1.567009	0.761375	2.150355
41	6	0	0.912143	1.348102	3.302990
42	6	0	0.061977	2.499896	2.802358
43	9	0	6.291274	-1.778483	2.192056
44	9	0	6.375903	0.112209	1.133615
45	9	0	5.184690	-0.057403	2.948863
46	6	0	0.749630	1.373606	-1.576833
47	6	0	0.576856	2.537328	-2.425785
48	8	0	-0.231518	2.517094	-3.353304
49	7	0	1.339621	3.654986	-2.143966
50	6	0	1.076826	4.848778	-2.951163
51	6	0	2.254826	3.749345	-1.051360
52	6	0	3.288007	2.816756	-0.893421
53	6	0	4.178507	2.931217	0.173973
54	6	0	4.068887	3.993624	1.072988
55	6	0	3.056609	4.940046	0.902315
56	6	0	2.148023	4.816908	-0.149264
57	1	0	-5.503836	-0.686805	2.600392
58	1	0	-7.855603	-0.189238	2.967647
59	1	0	-8.272468	0.840772	-1.179623
60	1	0	-10.163662	-0.475069	2.619191
61	1	0	-9.739636	1.221810	2.992719
62	1	0	-11.233214	0.851860	2.086990
63	1	0	-6.134569	-0.475310	-2.600184
64	1	0	-6.150600	1.269406	-2.445075
65	1	0	-3.898656	0.243683	-3.099487
66	1	0	-3.817452	1.310293	-1.703418
67	1	0	-1.578563	-2.647768	1.664609
68	1	0	-1.395189	-0.928062	1.345385
69	1	0	-3.572678	-1.331313	2.267222
70	1	0	-3.982883	-2.538063	1.067304
71	1	0	0.637182	-1.321606	-2.884174
72	1	0	-0.152881	-2.893544	-2.953881
73	1	0	-2.206907	-1.822441	-3.346588

74	1	0	-1.405754	-0.249770	-3.269175
75	1	0	-1.773388	-4.302652	-0.272950
76	1	0	-3.260742	-3.495460	-0.749478
77	1	0	-1.975389	-3.739465	-1.925341
78	1	0	1.506268	-4.716807	0.442446
79	1	0	1.231683	-3.149251	1.226039
80	1	0	-0.132368	-4.268119	0.967241
81	1	0	0.413526	-0.777183	0.724625
82	1	0	2.319830	-2.521178	-2.650949
83	1	0	4.411368	-3.268510	-3.730431
84	1	0	6.602824	-2.991639	-2.517099
85	1	0	6.614327	-1.979055	-0.244837
86	1	0	0.317687	0.575309	3.801079
87	1	0	1.682603	1.677615	4.006816
88	1	0	-0.444797	2.979018	3.647357
89	1	0	0.680438	3.246863	2.295697
90	1	0	-0.698993	2.149364	2.097583
91	1	0	1.976930	5.466308	-2.973759
92	1	0	0.811038	4.533013	-3.960490
93	1	0	0.242870	5.438805	-2.549995
94	1	0	3.391119	2.007151	-1.607211
95	1	0	4.965300	2.192532	0.297092
96	1	0	4.771512	4.086684	1.896292
97	1	0	2.966508	5.774920	1.592326
98	1	0	1.350529	5.544380	-0.268297

Free Energy and Geometry for R-120 (Conformer 2 of 4):



Sum of electronic and thermal free energies: -2450.029083 a.u.

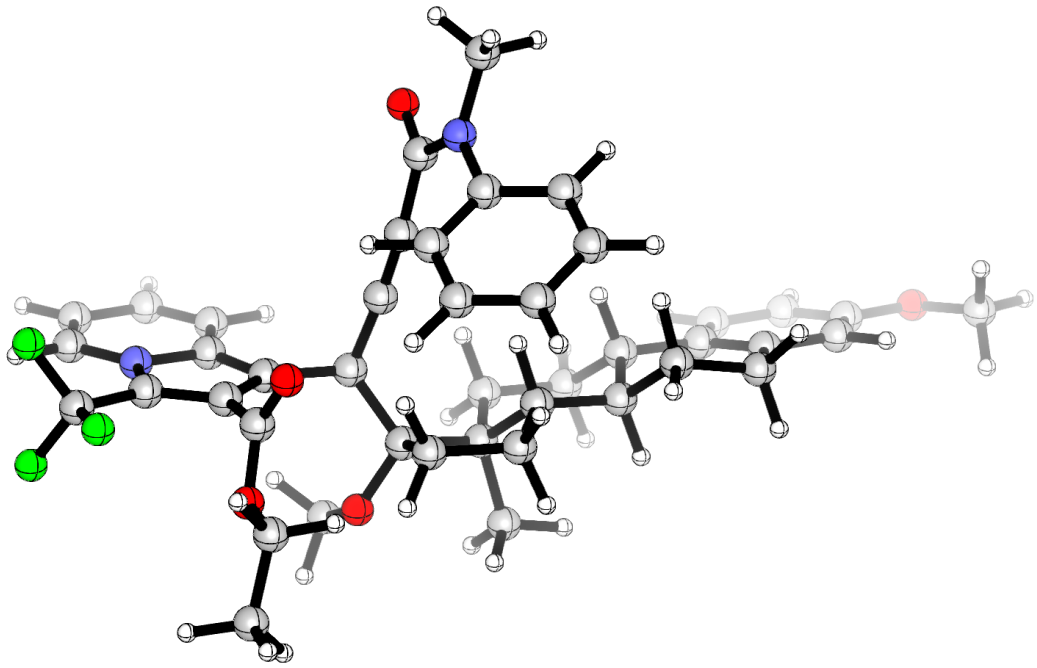
Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-5.886453	-2.115034	0.961479
2	6	0	-7.270754	-2.187995	1.012055
3	6	0	-8.038978	-1.360999	0.182935
4	6	0	-7.392674	-0.473176	-0.676381
5	6	0	-5.990534	-0.403511	-0.725407
6	6	0	-5.209738	-1.236132	0.095789
7	8	0	-9.396125	-1.495138	0.294767
8	6	0	-10.217594	-0.680925	-0.523152
9	6	0	-5.363384	0.575890	-1.703568
10	6	0	-3.876422	0.834951	-1.442586
11	6	0	-3.144895	-0.491780	-1.207205
12	6	0	-3.681082	-1.146258	0.093584
13	6	0	-1.622133	-0.350942	-1.096708
14	6	0	-0.894193	-1.707977	-0.892176
15	6	0	-1.429119	-2.352004	0.402538
16	6	0	-2.968244	-2.487565	0.385311
17	6	0	0.641307	-1.285026	-0.937309
18	6	0	0.640459	0.008673	-1.823817
19	6	0	-0.823932	0.314748	-2.222953
20	1	0	-3.394563	-0.462026	0.911740
21	1	0	-3.389945	-1.150619	-2.053875
22	1	0	-1.431998	0.246938	-0.193678
23	6	0	-1.139498	-2.681865	-2.072015

24	8	0	1.392324	-2.412406	-1.419832
25	6	0	2.268548	-2.290689	-2.522179
26	6	0	1.281423	-1.045574	0.495111
27	6	0	0.730550	0.062224	1.286177
28	6	0	2.805041	-1.025013	0.508880
29	6	0	3.555149	-2.094600	1.025753
30	7	0	4.920090	-1.778935	0.906046
31	6	0	5.030689	-0.540977	0.312110
32	6	0	3.742747	-0.064337	0.057461
33	6	0	3.213853	-3.347241	1.593787
34	6	0	4.193859	-4.204878	2.021160
35	6	0	5.564009	-3.838232	1.890271
36	6	0	5.908210	-2.640628	1.339546
37	6	0	6.358122	0.077864	0.069465
38	6	0	3.483131	1.240901	-0.620190
39	8	0	2.936328	2.202064	-0.122542
40	8	0	3.950150	1.215787	-1.885075
41	6	0	3.874761	2.461200	-2.620434
42	6	0	4.617971	2.259596	-3.927089
43	9	0	6.250190	1.356070	-0.336053
44	9	0	7.128196	0.075291	1.192672
45	9	0	7.081181	-0.590703	-0.867400
46	6	0	0.285896	0.920306	2.019670
47	6	0	-0.200308	1.756422	3.107262
48	8	0	-0.092436	1.370136	4.268549
49	7	0	-0.806852	2.958492	2.795155
50	6	0	-1.387731	3.700720	3.917248
51	6	0	-0.968703	3.471028	1.474690
52	6	0	-2.227665	3.928648	1.058543
53	6	0	-2.388532	4.480658	-0.212206
54	6	0	-1.301327	4.570223	-1.084181
55	6	0	-0.049281	4.112644	-0.668413
56	6	0	0.126001	3.578489	0.608237
57	1	0	-5.318630	-2.762861	1.621645
58	1	0	-7.776957	-2.873053	1.685157
59	1	0	-7.964565	0.183683	-1.324440
60	1	0	-10.064453	0.387202	-0.316997
61	1	0	-10.039328	-0.867467	-1.590980
62	1	0	-11.247077	-0.949982	-0.278162
63	1	0	-5.480917	0.177799	-2.723523
64	1	0	-5.924826	1.519468	-1.687951
65	1	0	-3.443868	1.373944	-2.293889
66	1	0	-3.748448	1.483902	-0.564910
67	1	0	-0.979713	-3.342015	0.562746
68	1	0	-1.162118	-1.732670	1.267345
69	1	0	-3.277688	-2.871310	1.363667
70	1	0	-3.285637	-3.238477	-0.348872
71	1	0	1.011238	0.844362	-1.226591
72	1	0	1.298549	-0.076755	-2.690091
73	1	0	-1.075314	-0.116967	-3.199518
74	1	0	-0.997316	1.393442	-2.288238
75	1	0	-0.646515	-3.636801	-1.877930
76	1	0	-2.204208	-2.874962	-2.220586

77	1	0	-0.743800	-2.301139	-3.018486
78	1	0	2.788150	-3.251181	-2.590403
79	1	0	1.732404	-2.123016	-3.468247
80	1	0	3.015540	-1.497806	-2.390905
81	1	0	1.015665	-1.953932	1.046635
82	1	0	2.166543	-3.614134	1.675200
83	1	0	3.931432	-5.163663	2.456096
84	1	0	6.351542	-4.505288	2.222785
85	1	0	6.927496	-2.306619	1.210736
86	1	0	2.820204	2.710200	-2.779201
87	1	0	4.319356	3.252524	-2.009661
88	1	0	4.589771	3.182428	-4.516547
89	1	0	5.664439	1.999633	-3.739890
90	1	0	4.163059	1.458742	-4.518799
91	1	0	-1.431477	4.759581	3.655607
92	1	0	-2.396578	3.345392	4.162900
93	1	0	-0.756667	3.555653	4.794697
94	1	0	-3.078966	3.847423	1.727935
95	1	0	-3.368201	4.835509	-0.521053
96	1	0	-1.428130	5.001592	-2.073440
97	1	0	0.812290	4.187421	-1.325947
98	1	0	1.108212	3.248595	0.923030

Free Energy and Geometry for R-120 (Conformer 3 of 4):



Sum of electronic and thermal free energies: -2450.026630 a.u.

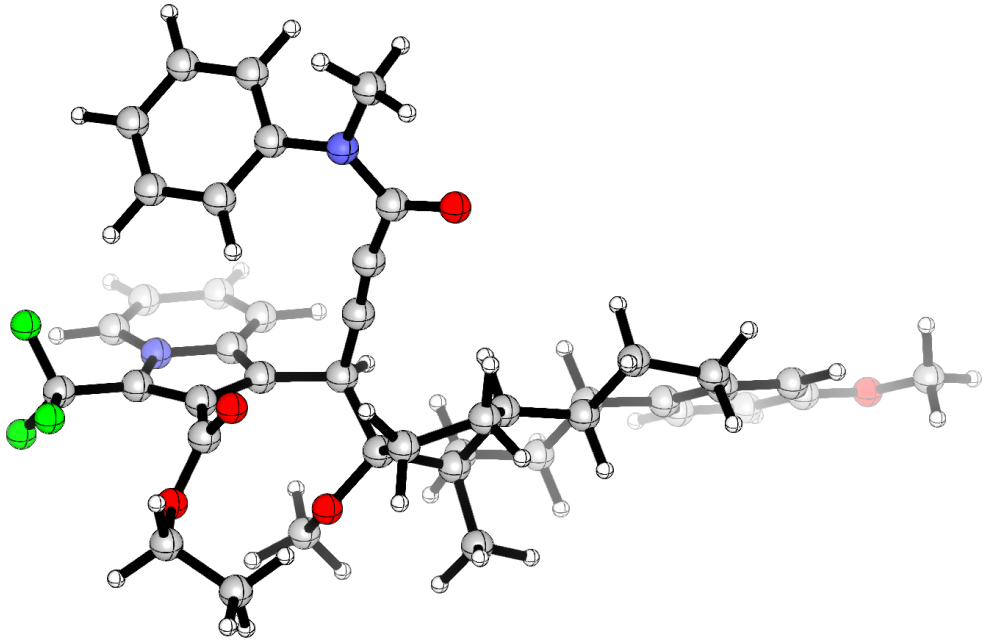
Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-5.965769	-2.243068	0.744764
2	6	0	-7.349699	-2.305811	0.815335
3	6	0	-8.120847	-1.318203	0.189591
4	6	0	-7.477677	-0.284606	-0.490481
5	6	0	-6.076047	-0.225705	-0.560843
6	6	0	-5.292855	-1.217130	0.056254
7	8	0	-9.477202	-1.453547	0.307155
8	6	0	-10.301794	-0.479399	-0.307829
9	6	0	-5.453344	0.921149	-1.339878
10	6	0	-3.952952	1.095196	-1.084110
11	6	0	-3.248296	-0.266252	-1.135123
12	6	0	-3.763631	-1.147347	0.031517
13	6	0	-1.719845	-0.170025	-1.056094
14	6	0	-0.996224	-1.549216	-1.115648
15	6	0	-1.524019	-2.405526	0.055440
16	6	0	-3.064143	-2.524820	0.039995
17	6	0	0.544098	-1.108960	-1.115873
18	6	0	0.514311	0.285878	-1.823867
19	6	0	-0.959583	0.677057	-2.081916
20	1	0	-3.445918	-0.636142	0.957558
21	1	0	-3.538184	-0.743404	-2.083370

22	1	0	-1.492402	0.259414	-0.070805
23	6	0	-1.284259	-2.267536	-2.459988
24	8	0	1.367125	-1.937307	-1.942614
25	6	0	1.624218	-3.276802	-1.550691
26	6	0	1.186615	-1.056309	0.335590
27	6	0	0.659419	-0.006401	1.217537
28	6	0	2.713916	-1.035691	0.427301
29	6	0	3.391355	-1.906286	1.300847
30	7	0	4.770190	-1.655862	1.197546
31	6	0	4.958072	-0.637546	0.288600
32	6	0	3.709291	-0.239107	-0.188984
33	6	0	2.970794	-2.912441	2.207290
34	6	0	3.892645	-3.618621	2.936575
35	6	0	5.280994	-3.339832	2.786829
36	6	0	5.699123	-2.367951	1.927927
37	6	0	6.319915	-0.138515	-0.025148
38	6	0	3.558578	0.914467	-1.131305
39	8	0	3.182677	2.020587	-0.799217
40	8	0	3.929561	0.583864	-2.376027
41	6	0	3.935013	1.658489	-3.347928
42	6	0	4.445922	1.081623	-4.654010
43	9	0	7.092818	-1.086600	-0.619142
44	9	0	6.286955	0.929549	-0.841605
45	9	0	6.996297	0.228878	1.097721
46	6	0	0.297045	0.844417	2.002761
47	6	0	-0.113896	1.688440	3.113878
48	8	0	-0.154597	1.228855	4.252943
49	7	0	-0.464823	2.996538	2.842899
50	6	0	-0.958880	3.781223	3.977428
51	6	0	-0.487292	3.580973	1.540295
52	6	0	-1.643537	4.243327	1.102841
53	6	0	-1.668557	4.859300	-0.148045
54	6	0	-0.547635	4.809426	-0.979647
55	6	0	0.602531	4.147270	-0.545467
56	6	0	0.642667	3.547961	0.713842
57	1	0	-5.395454	-3.018371	1.246452
58	1	0	-7.853356	-3.105379	1.349768
59	1	0	-8.051758	0.496848	-0.978571
60	1	0	-10.123845	0.522671	0.105642
61	1	0	-10.151547	-0.448706	-1.395614
62	1	0	-11.330221	-0.778300	-0.095213
63	1	0	-5.611374	0.741550	-2.414684
64	1	0	-5.990235	1.851880	-1.113624
65	1	0	-3.532120	1.782448	-1.827209
66	1	0	-3.783488	1.556297	-0.100494
67	1	0	-1.089498	-3.414475	0.045184
68	1	0	-1.239050	-1.945979	1.010634
69	1	0	-3.361219	-3.093061	0.928359
70	1	0	-3.398448	-3.113311	-0.823838
71	1	0	0.973363	1.041790	-1.187029
72	1	0	1.104545	0.218129	-2.741145
73	1	0	-1.270889	0.430505	-3.104398
74	1	0	-1.114607	1.751441	-1.944711

75	1	0	-0.923281	-3.299549	-2.444698
76	1	0	-2.355542	-2.311128	-2.667989
77	1	0	-0.799358	-1.773224	-3.303982
78	1	0	2.336061	-3.337592	-0.719378
79	1	0	0.715283	-3.825510	-1.277624
80	1	0	2.071307	-3.762429	-2.422939
81	1	0	0.899912	-2.007560	0.798858
82	1	0	1.909502	-3.101386	2.325032
83	1	0	3.568270	-4.383954	3.633963
84	1	0	6.022670	-3.889653	3.355257
85	1	0	6.735501	-2.103238	1.775119
86	1	0	2.917810	2.051772	-3.439753
87	1	0	4.574859	2.462463	-2.970815
88	1	0	4.466767	1.863104	-5.421425
89	1	0	5.459728	0.686845	-4.534741
90	1	0	3.798145	0.271093	-5.002430
91	1	0	-0.807184	4.841110	3.765277
92	1	0	-2.023827	3.597639	4.168781
93	1	0	-0.402809	3.492626	4.870175
94	1	0	-2.522664	4.269345	1.739981
95	1	0	-2.569682	5.372138	-0.473895
96	1	0	-0.569312	5.288459	-1.954801
97	1	0	1.486402	4.094814	-1.173421
98	1	0	1.549992	3.054631	1.041376

Free Energy and Geometry for R-120 (Conformer 4 of 4):



Sum of electronic and thermal free energies: -2450.027834 a.u.

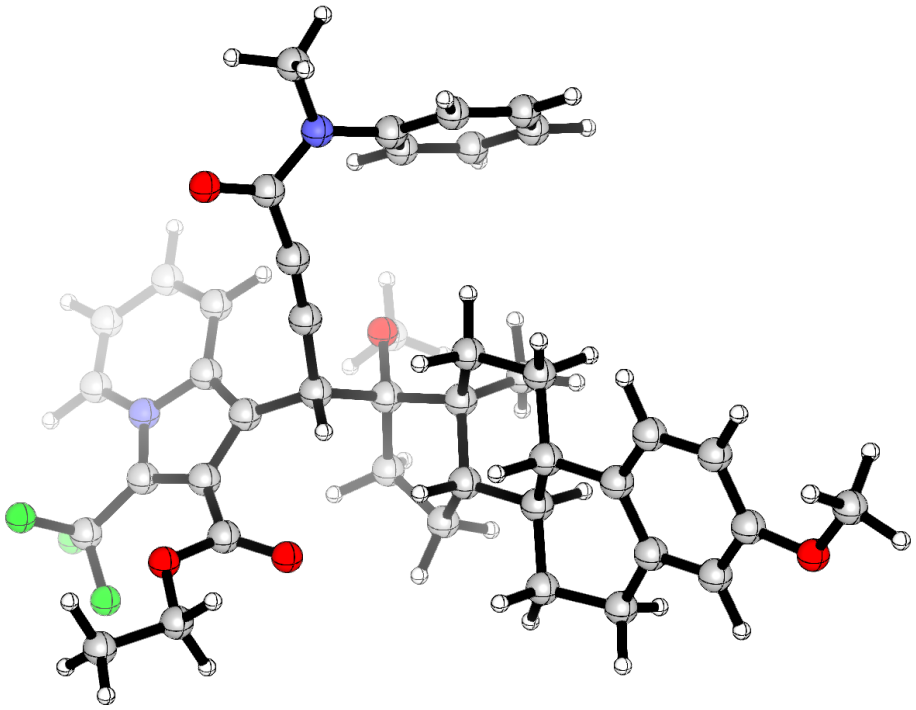
Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-6.440295	-0.878438	1.861348
2	6	0	-7.802368	-0.726649	2.075914
3	6	0	-8.571384	-0.001096	1.157276
4	6	0	-7.947473	0.560214	0.043606
5	6	0	-6.568318	0.403014	-0.170978
6	6	0	-5.789032	-0.331305	0.740671
7	8	0	-9.905323	0.102209	1.442644
8	6	0	-10.726543	0.827784	0.544281
9	6	0	-5.968327	1.029124	-1.418921
10	6	0	-4.439362	1.111590	-1.387954
11	6	0	-3.849724	-0.222687	-0.915705
12	6	0	-4.276485	-0.477602	0.552499
13	6	0	-2.321411	-0.284796	-1.011314
14	6	0	-1.726291	-1.647719	-0.558024
15	6	0	-2.169610	-1.921790	0.896645
16	6	0	-3.701706	-1.812945	1.074779
17	6	0	-0.191023	-1.400351	-0.887138
18	6	0	-0.284334	-0.748854	-2.299998
19	6	0	-1.643500	0.000558	-2.369522
20	1	0	-3.795952	0.320675	1.146521
21	1	0	-4.283762	-1.014236	-1.546179
22	1	0	-1.948314	0.473794	-0.306608

23	6	0	-2.228671	-2.811187	-1.453055
24	8	0	0.595091	-2.576987	-1.048166
25	6	0	0.688688	-3.504888	0.024497
26	6	0	0.524232	-0.405860	0.169548
27	6	0	0.547964	0.988342	-0.285052
28	6	0	1.922367	-0.778640	0.646986
29	6	0	2.286426	-0.743754	2.002231
30	7	0	3.654081	-1.060358	2.098464
31	6	0	4.138853	-1.293858	0.828412
32	6	0	3.087640	-1.124182	-0.075536
33	6	0	1.585645	-0.467743	3.203315
34	6	0	2.233727	-0.512740	4.410574
35	6	0	3.619846	-0.837359	4.459598
36	6	0	4.306992	-1.103385	3.313228
37	6	0	5.591296	-1.509475	0.610065
38	6	0	3.208045	-1.269099	-1.555981
39	8	0	2.972610	-0.376118	-2.345650
40	8	0	3.634152	-2.497062	-1.893679
41	6	0	3.883519	-2.742680	-3.301134
42	6	0	2.628872	-3.221564	-4.013622
43	9	0	6.327171	-0.490454	1.150153
44	9	0	6.048951	-2.639240	1.211636
45	9	0	5.911015	-1.576632	-0.689966
46	6	0	0.627996	2.140843	-0.650974
47	6	0	0.545141	3.448879	-1.273000
48	8	0	-0.439005	3.755666	-1.945543
49	7	0	1.600347	4.318326	-1.081893
50	6	0	1.458629	5.654219	-1.665565
51	6	0	2.741610	4.039518	-0.267774
52	6	0	3.519937	2.892326	-0.475316
53	6	0	4.637339	2.659616	0.327756
54	6	0	5.006629	3.574182	1.315721
55	6	0	4.244384	4.727465	1.506520
56	6	0	3.113088	4.957087	0.724794
57	1	0	-5.869847	-1.439582	2.594942
58	1	0	-8.289938	-1.156816	2.945319
59	1	0	-8.519165	1.133236	-0.679672
60	1	0	-10.414683	1.878232	0.467581
61	1	0	-10.724365	0.380369	-0.458938
62	1	0	-11.736633	0.781878	0.956348
63	1	0	-6.274974	0.433393	-2.292726
64	1	0	-6.401434	2.025973	-1.573220
65	1	0	-4.063781	1.374430	-2.383341
66	1	0	-4.114577	1.913520	-0.709845
67	1	0	-1.842622	-2.912955	1.234115
68	1	0	-1.712745	-1.195711	1.582375
69	1	0	-3.917713	-1.926535	2.143008
70	1	0	-4.209361	-2.647734	0.575854
71	1	0	0.567032	-0.099607	-2.498591
72	1	0	-0.238347	-1.562401	-3.028651
73	1	0	-2.253138	-0.376631	-3.199938
74	1	0	-1.505839	1.073711	-2.526521
75	1	0	-1.737639	-3.751467	-1.191046

76	1	0	-3.303747	-2.964666	-1.336091
77	1	0	-2.043157	-2.634810	-2.514306
78	1	0	-0.173232	-4.183416	0.051141
79	1	0	1.594118	-4.089552	-0.159272
80	1	0	0.783395	-3.018574	1.001001
81	1	0	-0.097288	-0.414118	1.069967
82	1	0	0.533393	-0.210937	3.146926
83	1	0	1.697129	-0.298659	5.329059
84	1	0	4.147179	-0.878415	5.406078
85	1	0	5.356158	-1.360355	3.286193
86	1	0	4.274115	-1.827379	-3.752214
87	1	0	4.663441	-3.508214	-3.301055
88	1	0	2.874391	-3.490712	-5.047707
89	1	0	2.209369	-4.100814	-3.515365
90	1	0	1.869732	-2.436131	-4.029253
91	1	0	2.452529	6.068983	-1.844087
92	1	0	0.912599	5.566642	-2.605515
93	1	0	0.896244	6.330637	-1.009138
94	1	0	3.253784	2.185317	-1.253892
95	1	0	5.228075	1.761101	0.175577
96	1	0	5.884825	3.391054	1.928781
97	1	0	4.521855	5.447532	2.271868
98	1	0	2.509392	5.844771	0.889071

Free Energy and Geometry for S-120 (Conformer 1 of 5):



Sum of electronic and thermal free energies: -2450.035676 a.u.

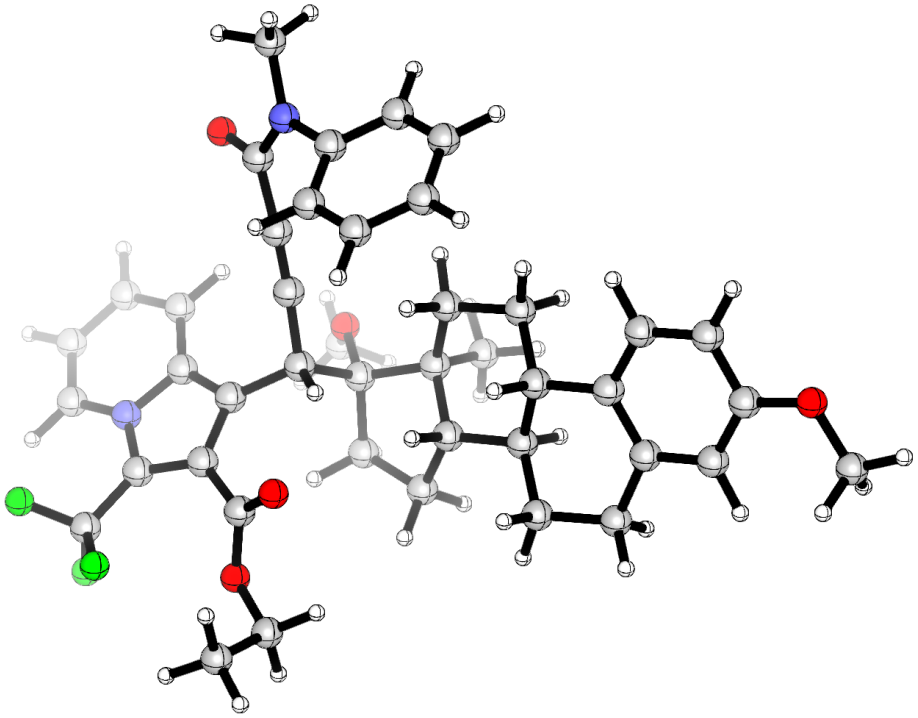
Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	5.877713	-0.364463	0.849866
2	6	0	7.225272	-0.678170	1.037286
3	6	0	7.733016	-1.853970	0.478482
4	6	0	6.878074	-2.684681	-0.251162
5	6	0	5.532569	-2.366562	-0.438212
6	6	0	5.005659	-1.178278	0.117526
7	6	0	4.678027	-3.309773	-1.268489
8	6	0	3.173286	-3.064472	-1.119712
9	6	0	2.869174	-1.564693	-1.223065
10	6	0	3.521749	-0.828988	-0.024491
11	6	0	1.370867	-1.240791	-1.254138
12	6	0	1.072433	0.275945	-1.391004
13	6	0	1.718683	1.001713	-0.193658
14	6	0	3.226160	0.686886	-0.069458
15	6	0	-0.509220	0.274662	-1.524485
16	6	0	-0.775002	-1.002071	-2.394187
17	6	0	0.488880	-1.901006	-2.323012
18	8	0	9.029954	-2.277778	0.588386
19	6	0	9.931671	-1.473413	1.327901
20	1	0	3.010351	-1.216437	0.874905

21	1	0	3.335488	-1.200120	-2.151644
22	1	0	0.970532	-1.561622	-0.281236
23	6	0	1.643341	0.873056	-2.699197
24	8	0	-0.991300	1.521621	-2.069960
25	6	0	-1.471710	1.613773	-3.398124
26	6	0	-1.247325	0.164805	-0.124063
27	6	0	-1.192939	1.409549	0.657047
28	6	0	-2.693905	-0.305373	-0.197776
29	6	0	-3.807917	0.446374	-0.599232
30	7	0	-4.953309	-0.364662	-0.463028
31	6	0	-4.573350	-1.598096	0.023683
32	6	0	-3.187538	-1.567061	0.217460
33	6	0	-3.980990	1.780012	-1.047623
34	6	0	-5.231875	2.250614	-1.349198
35	6	0	-6.362107	1.395639	-1.209520
36	6	0	-6.212989	0.113529	-0.773973
37	6	0	-1.200186	2.413514	1.336770
38	6	0	-2.343183	-2.627459	0.822408
39	6	0	-5.561902	-2.698910	0.197946
40	9	0	-6.330282	-2.550913	1.304622
41	9	0	-6.433150	-2.747530	-0.852277
42	9	0	-4.974849	-3.905000	0.265041
43	8	0	-1.211759	-2.897349	0.456780
44	8	0	-2.947626	-3.221565	1.863187
45	6	0	-2.227962	-4.310086	2.490958
46	6	0	-3.147871	-4.908555	3.537678
47	6	0	-1.325500	3.499453	2.292957
48	8	0	-2.080336	3.401981	3.257011
49	7	0	-0.550906	4.629907	2.090409
50	6	0	0.367162	4.801672	1.012327
51	6	0	-0.605780	5.653419	3.137035
52	6	0	-0.058428	4.699629	-0.318005
53	6	0	0.846186	4.905512	-1.359130
54	6	0	2.174629	5.238994	-1.088143
55	6	0	2.597128	5.356758	0.237297
56	6	0	1.701917	5.134521	1.283118
57	1	0	5.506426	0.550303	1.301093
58	1	0	7.853791	-0.008531	1.613552
59	1	0	7.290061	-3.597214	-0.674904
60	1	0	4.953088	-3.189724	-2.327691
61	1	0	4.925258	-4.348382	-1.013950
62	1	0	2.632920	-3.627569	-1.889904
63	1	0	2.819467	-3.440346	-0.148858
64	1	0	1.574667	2.084754	-0.265069
65	1	0	1.237626	0.686004	0.739174
66	1	0	3.586522	1.167891	0.846859
67	1	0	3.791916	1.144989	-0.890518
68	1	0	-1.655959	-1.535483	-2.036049
69	1	0	-0.985693	-0.724327	-3.428185
70	1	0	1.002285	-1.931462	-3.292253
71	1	0	0.229309	-2.929351	-2.059300
72	1	0	10.893919	-1.988229	1.291310
73	1	0	10.040109	-0.473381	0.886197

74	1	0	9.617415	-1.368868	2.375346
75	1	0	1.357639	1.925734	-2.775909
76	1	0	2.733991	0.823337	-2.725554
77	1	0	1.280067	0.356462	-3.593330
78	1	0	-0.713860	1.360140	-4.150021
79	1	0	-2.365742	0.999449	-3.568967
80	1	0	-1.747544	2.664162	-3.535633
81	1	0	-0.711255	-0.600428	0.445792
82	1	0	-3.094523	2.393539	-1.137135
83	1	0	-5.367841	3.273258	-1.685949
84	1	0	-7.360258	1.752703	-1.438302
85	1	0	-7.034517	-0.573619	-0.640448
86	1	0	-1.948871	-5.035534	1.720505
87	1	0	-1.305027	-3.913176	2.925784
88	1	0	-2.649873	-5.749018	4.033126
89	1	0	-3.411860	-4.166271	4.297444
90	1	0	-4.070760	-5.273077	3.075947
91	1	0	-0.341007	6.619336	2.702266
92	1	0	-1.619291	5.685973	3.538331
93	1	0	0.078695	5.429481	3.965368
94	1	0	-1.094077	4.461442	-0.530963
95	1	0	0.504018	4.818576	-2.386614
96	1	0	2.873461	5.409175	-1.902313
97	1	0	3.628845	5.614507	0.460988
98	1	0	2.037152	5.210988	2.313216

Free Energy and Geometry for S-120 (Conformer 2 of 5):



Sum of electronic and thermal free energies: -2450.036571 a.u.

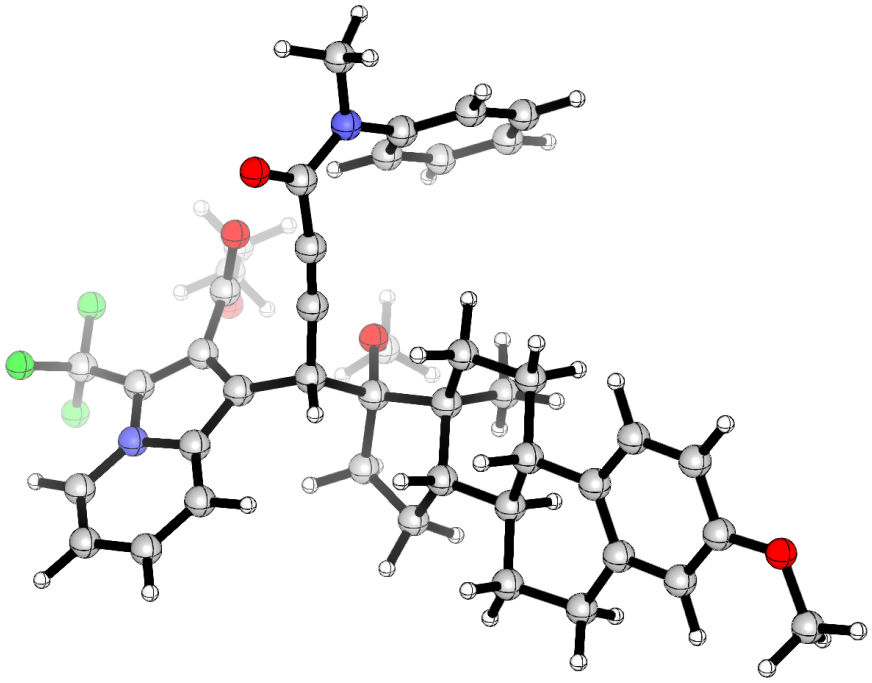
Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-5.826484	0.417211	-0.120568
2	6	0	-7.188902	0.233510	-0.305650
3	6	0	-7.734920	-1.052422	-0.205152
4	6	0	-6.892208	-2.127409	0.075343
5	6	0	-5.513252	-1.936581	0.263332
6	6	0	-4.956372	-0.648723	0.173299
7	6	0	-4.666020	-3.156200	0.586239
8	6	0	-3.161979	-2.915822	0.423181
9	6	0	-2.765462	-1.588919	1.081595
10	6	0	-3.450593	-0.420081	0.327837
11	6	0	-1.252779	-1.341475	1.114529
12	6	0	-0.864179	-0.013969	1.817270
13	6	0	-1.547717	1.145000	1.066046
14	6	0	-3.074935	0.943839	0.950373
15	6	0	0.718917	-0.105113	1.806787
16	6	0	0.960463	-1.619216	2.125705
17	6	0	-0.337040	-2.393951	1.760417
18	8	0	-9.085728	-1.146516	-0.401891
19	6	0	-9.686804	-2.426089	-0.309388
20	1	0	-3.015919	-0.423640	-0.687701

21	1	0	-3.147445	-1.609640	2.114140
22	1	0	-0.939990	-1.252007	0.062914
23	6	0	-1.307649	0.024780	3.299714
24	8	0	1.299910	0.832731	2.727804
25	6	0	1.943241	0.411627	3.915469
26	6	0	1.352786	0.293634	0.403929
27	6	0	1.302136	1.743220	0.173766
28	6	0	2.783309	-0.179499	0.196003
29	6	0	3.955449	0.412269	0.691877
30	7	0	5.050550	-0.352039	0.238462
31	6	0	4.580732	-1.398042	-0.530304
32	6	0	3.184534	-1.312328	-0.553073
33	6	0	4.219237	1.564417	1.477244
34	6	0	5.509125	1.895797	1.799086
35	6	0	6.585404	1.078773	1.350145
36	6	0	6.348963	-0.020300	0.580890
37	6	0	1.307254	2.933254	-0.054203
38	6	0	2.236365	-2.256873	-1.199195
39	6	0	5.507064	-2.342090	-1.212754
40	9	0	4.911749	-2.982979	-2.234124
41	9	0	6.584551	-1.690609	-1.736610
42	9	0	6.017610	-3.282894	-0.379133
43	8	0	1.230614	-1.918211	-1.796808
44	8	0	2.585733	-3.540382	-0.982346
45	6	0	1.772402	-4.559178	-1.617200
46	6	0	2.223089	-4.811213	-3.048148
47	6	0	1.476972	4.371061	-0.148685
48	8	0	2.419497	4.928101	0.410913
49	7	0	0.530845	5.078494	-0.868953
50	6	0	-0.607068	4.482134	-1.492045
51	6	0	0.645475	6.537924	-0.859669
52	6	0	-1.893684	4.934899	-1.171570
53	6	0	-3.009208	4.381768	-1.800750
54	6	0	-2.853330	3.364940	-2.744986
55	6	0	-1.571008	2.914977	-3.066992
56	6	0	-0.450773	3.478626	-2.456952
57	1	0	-5.429990	1.423464	-0.211272
58	1	0	-7.847384	1.067125	-0.529808
59	1	0	-7.288834	-3.135014	0.152058
60	1	0	-4.866002	-3.458990	1.625822
61	1	0	-4.987860	-4.001762	-0.035810
62	1	0	-2.607781	-3.753528	0.863973
63	1	0	-2.895567	-2.885881	-0.643385
64	1	0	-1.336914	2.104464	1.552251
65	1	0	-1.148415	1.222268	0.049376
66	1	0	-3.462854	1.759228	0.330501
67	1	0	-3.563243	1.045884	1.927865
68	1	0	1.830268	-2.006655	1.592856
69	1	0	1.183010	-1.745973	3.186245
70	1	0	-0.800018	-2.818391	2.659636
71	1	0	-0.132455	-3.232164	1.086851
72	1	0	-10.752021	-2.272092	-0.493277
73	1	0	-9.286361	-3.118172	-1.062682

74	1	0	-9.551876	-2.866697	0.687820
75	1	0	-0.939162	0.943502	3.764382
76	1	0	-2.395172	0.014425	3.399537
77	1	0	-0.925947	-0.821174	3.880432
78	1	0	1.260454	-0.075322	4.624924
79	1	0	2.794904	-0.254169	3.722810
80	1	0	2.320695	1.327223	4.380088
81	1	0	0.758473	-0.188205	-0.378125
82	1	0	3.379238	2.169213	1.792016
83	1	0	5.713249	2.782640	2.389819
84	1	0	7.610834	1.319044	1.609285
85	1	0	7.125605	-0.670772	0.208602
86	1	0	1.916936	-5.441293	-0.989162
87	1	0	0.725423	-4.249563	-1.575678
88	1	0	1.651317	-5.643378	-3.474632
89	1	0	2.054249	-3.925975	-3.667935
90	1	0	3.286402	-5.066170	-3.080087
91	1	0	0.131664	6.984401	0.001552
92	1	0	1.701978	6.799918	-0.795936
93	1	0	0.212996	6.934869	-1.780670
94	1	0	-2.018941	5.712152	-0.423572
95	1	0	-4.001907	4.743352	-1.545990
96	1	0	-3.722939	2.931861	-3.231199
97	1	0	-1.437541	2.132840	-3.809265
98	1	0	0.546350	3.147124	-2.725456

Free Energy and Geometry for S-120 (Conformer 3 of 5):



Sum of electronic and thermal free energies: -2450.026304 a.u.

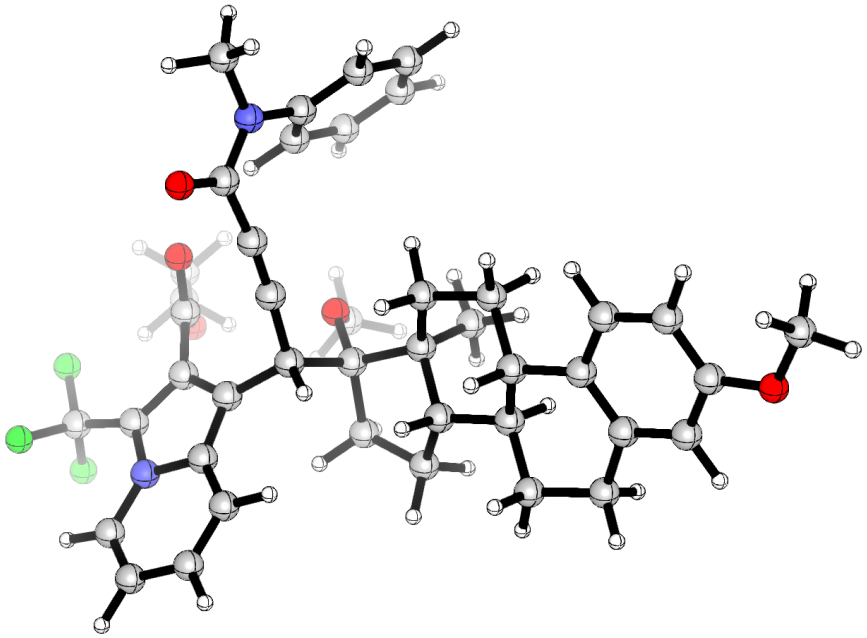
Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-6.251894	0.570739	-0.811455
2	6	0	-7.636359	0.568739	-0.894616
3	6	0	-8.360087	-0.517015	-0.385186
4	6	0	-7.669504	-1.581289	0.193630
5	6	0	-6.267334	-1.574449	0.276823
6	6	0	-5.532093	-0.485590	-0.223389
7	6	0	-5.591013	-2.762363	0.940635
8	6	0	-4.084738	-2.836294	0.672131
9	6	0	-3.444988	-1.457368	0.874801
10	6	0	-4.001653	-0.474562	-0.186575
11	6	0	-1.913632	-1.465479	0.796428
12	6	0	-1.274670	-0.071590	1.042066
13	6	0	-1.833069	0.902224	-0.016600
14	6	0	-3.377989	0.930304	-0.026721
15	6	0	0.277910	-0.425980	1.024446
16	6	0	0.314462	-1.830796	1.723452
17	6	0	-1.125425	-2.410618	1.714324
18	8	0	-9.720174	-0.440255	-0.507800
19	6	0	-10.498205	-1.514906	-0.010494
20	1	0	-3.650747	-0.857534	-1.162030
21	1	0	-3.747070	-1.101497	1.871761

22	1	0	-1.669458	-1.747219	-0.241937
23	6	0	-1.612204	0.489181	2.443587
24	8	0	1.083264	0.593134	1.636071
25	6	0	1.548129	0.474101	2.969901
26	6	0	0.869248	-0.525671	-0.442004
27	6	0	0.962484	0.760780	-1.145138
28	6	0	2.204982	-1.246258	-0.549072
29	6	0	2.342610	-2.515276	-1.133356
30	7	0	3.701447	-2.878262	-1.086425
31	6	0	4.405249	-1.853939	-0.489230
32	6	0	3.502587	-0.844033	-0.147171
33	6	0	1.432259	-3.431268	-1.718940
34	6	0	1.875232	-4.630861	-2.212546
35	6	0	3.258624	-4.960812	-2.134433
36	6	0	4.146401	-4.088702	-1.579438
37	6	0	1.064056	1.780583	-1.789429
38	6	0	3.929277	0.442593	0.488087
39	6	0	5.881733	-1.936708	-0.334190
40	9	0	6.256136	-2.865930	0.584241
41	9	0	6.485092	-2.309932	-1.497114
42	9	0	6.422562	-0.762279	0.031638
43	8	0	3.847098	1.538292	-0.018100
44	8	0	4.488441	0.211630	1.696221
45	6	0	5.137573	1.345343	2.317504
46	6	0	5.877159	0.829782	3.537390
47	6	0	1.226537	2.900824	-2.697015
48	8	0	1.500894	2.714935	-3.880320
49	7	0	1.035206	4.172945	-2.186819
50	6	0	0.656498	4.457343	-0.840433
51	6	0	1.106675	5.274918	-3.148193
52	6	0	1.416146	3.983848	0.237151
53	6	0	1.034934	4.300602	1.541037
54	6	0	-0.079606	5.104846	1.786115
55	6	0	-0.825898	5.589568	0.710397
56	6	0	-0.464699	5.263903	-0.596441
57	1	0	-5.718011	1.422165	-1.221234
58	1	0	-8.176856	1.392446	-1.350594
59	1	0	-8.205899	-2.437816	0.589937
60	1	0	-5.754092	-2.699634	2.027715
61	1	0	-6.081789	-3.690774	0.620512
62	1	0	-3.630956	-3.582011	1.336089
63	1	0	-3.900118	-3.175036	-0.358095
64	1	0	-1.445390	1.914647	0.139916
65	1	0	-1.503435	0.600017	-1.016354
66	1	0	-3.686866	1.574127	-0.857529
67	1	0	-3.772047	1.403572	0.881229
68	1	0	1.015280	-2.494924	1.213900
69	1	0	0.683034	-1.741669	2.746361
70	1	0	-1.552562	-2.414064	2.724475
71	1	0	-1.143464	-3.447584	1.363507
72	1	0	-11.538735	-1.249064	-0.207289
73	1	0	-10.262741	-2.457512	-0.523083
74	1	0	-10.357875	-1.651190	1.070465

75	1	0	-1.077644	1.430941	2.595343
76	1	0	-2.679066	0.695778	2.550179
77	1	0	-1.339341	-0.193835	3.254050
78	1	0	2.298768	-0.317383	3.081320
79	1	0	2.025336	1.433107	3.191758
80	1	0	0.744531	0.319064	3.698709
81	1	0	0.156091	-1.134986	-1.011380
82	1	0	0.382823	-3.162378	-1.770984
83	1	0	1.178191	-5.329544	-2.663476
84	1	0	3.625955	-5.907233	-2.515143
85	1	0	5.205850	-4.281393	-1.495721
86	1	0	5.813747	1.800856	1.587879
87	1	0	4.378178	2.090277	2.577029
88	1	0	6.395701	1.656209	4.035535
89	1	0	5.186802	0.373862	4.254627
90	1	0	6.618863	0.078871	3.247804
91	1	0	1.364065	6.192507	-2.615470
92	1	0	1.873166	5.041863	-3.888257
93	1	0	0.156977	5.418970	-3.679811
94	1	0	2.293395	3.373016	0.056190
95	1	0	1.629698	3.928215	2.370892
96	1	0	-0.361205	5.357093	2.804942
97	1	0	-1.696153	6.216590	0.885877
98	1	0	-1.056035	5.628311	-1.431408

Free Energy and Geometry for S-120 (Conformer 4 of 5):



Sum of electronic and thermal free energies: -2450.026281 a.u.

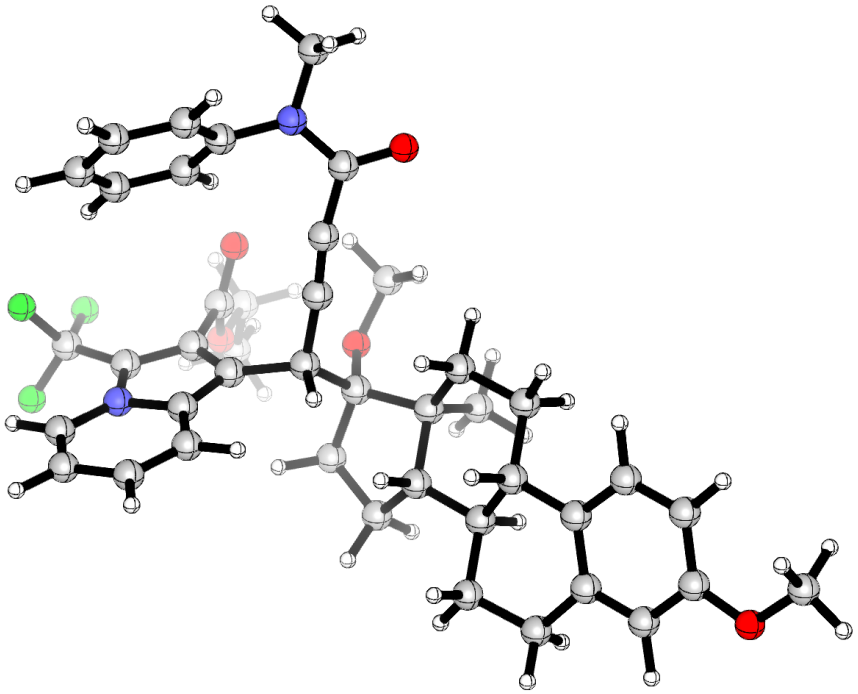
Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	-6.282315	0.291505	-0.674997
2	6	0	-7.675649	0.239783	-0.743406
3	6	0	-8.339924	-0.881704	-0.239342
4	6	0	-7.591127	-1.922233	0.317718
5	6	0	-6.198864	-1.865729	0.386194
6	6	0	-5.513748	-0.735695	-0.115175
7	6	0	-5.462357	-3.027156	1.032447
8	6	0	-3.958526	-3.035560	0.740934
9	6	0	-3.373090	-1.632514	0.944168
10	6	0	-3.984279	-0.667301	-0.103757
11	6	0	-1.843888	-1.578942	0.843194
12	6	0	-1.256567	-0.161983	1.084091
13	6	0	-1.866759	0.791441	0.035689
14	6	0	-3.411571	0.759750	0.047930
15	6	0	0.308057	-0.455606	1.043966
16	6	0	0.408718	-1.856417	1.743890
17	6	0	-1.005941	-2.495710	1.746035
18	8	0	-9.696519	-1.057820	-0.246188
19	6	0	-10.497855	-0.033628	-0.809662

20	1	0	-3.636318	-1.036037	-1.085698
21	1	0	-3.674382	-1.295146	1.947780
22	1	0	-1.604669	-1.847727	-0.199748
23	6	0	-1.596158	0.381899	2.491754
24	8	0	1.082302	0.594777	1.642666
25	6	0	1.571052	0.495906	2.969625
26	6	0	0.880810	-0.534226	-0.431140
27	6	0	0.917140	0.754838	-1.134762
28	6	0	2.239564	-1.206777	-0.558541
29	6	0	2.412889	-2.470880	-1.144040
30	7	0	3.784134	-2.785985	-1.117057
31	6	0	4.460352	-1.737054	-0.530787
32	6	0	3.527986	-0.759048	-0.175893
33	6	0	1.526510	-3.419024	-1.715014
34	6	0	2.003817	-4.603053	-2.214155
35	6	0	3.398959	-4.884139	-2.156680
36	6	0	4.263850	-3.980697	-1.615844
37	6	0	0.972201	1.777419	-1.780335
38	6	0	3.918340	0.541980	0.453290
39	6	0	5.940880	-1.768016	-0.397199
40	9	0	6.360865	-2.682836	0.515946
41	9	0	6.540053	-2.120738	-1.568647
42	9	0	6.445456	-0.575041	-0.039538
43	8	0	3.790533	1.633967	-0.051535
44	8	0	4.502270	0.331259	1.653351
45	6	0	5.120144	1.487104	2.265606
46	6	0	5.896873	0.997638	3.473109
47	6	0	1.082360	2.901533	-2.690873
48	8	0	1.342893	2.723659	-3.878558
49	7	0	0.858290	4.167434	-2.178437
50	6	0	0.490692	4.441474	-0.826850
51	6	0	0.879863	5.269793	-3.141760
52	6	0	1.279687	3.992599	0.240144
53	6	0	0.907574	4.299253	1.549063
54	6	0	-0.227197	5.069651	1.809493
55	6	0	-1.003066	5.530226	0.744180
56	6	0	-0.650853	5.213985	-0.567405
57	1	0	-5.790784	1.169918	-1.081048
58	1	0	-8.218694	1.066425	-1.187397
59	1	0	-8.124902	-2.788421	0.700775
60	1	0	-5.610328	-2.974304	2.121954
61	1	0	-5.919651	-3.973433	0.716545
62	1	0	-3.464193	-3.766036	1.392726
63	1	0	-3.774695	-3.359427	-0.294267
64	1	0	-1.516072	1.817801	0.189084
65	1	0	-1.539757	0.503887	-0.969238
66	1	0	-3.757093	1.391242	-0.778043
67	1	0	-3.810121	1.217546	0.961817
68	1	0	1.133912	-2.491294	1.231245
69	1	0	0.779223	-1.749293	2.764361
70	1	0	-1.421178	-2.523599	2.760744
71	1	0	-0.984778	-3.530187	1.388275
72	1	0	-11.531030	-0.373620	-0.714512

73	1	0	-10.379138	0.916705	-0.271704
74	1	0	-10.265830	0.125092	-1.871513
75	1	0	-1.096684	1.343454	2.638959
76	1	0	-2.668680	0.546388	2.613809
77	1	0	-1.285638	-0.292045	3.296260
78	1	0	2.016414	1.472151	3.182359
79	1	0	0.784530	0.313771	3.710706
80	1	0	2.351465	-0.267584	3.071555
81	1	0	0.181698	-1.168570	-0.990369
82	1	0	0.467585	-3.187309	-1.751272
83	1	0	1.324990	-5.326486	-2.653691
84	1	0	3.793480	-5.817641	-2.542052
85	1	0	5.330544	-4.136027	-1.547901
86	1	0	5.767974	1.967021	1.525980
87	1	0	4.338723	2.204164	2.537968
88	1	0	6.393343	1.841801	3.963950
89	1	0	5.234727	0.516877	4.200647
90	1	0	6.660274	0.273921	3.170951
91	1	0	1.114427	6.196066	-2.613563
92	1	0	1.643047	5.061101	-3.892444
93	1	0	-0.081433	5.381816	-3.660121
94	1	0	2.172575	3.408667	0.047300
95	1	0	1.525133	3.946133	2.370637
96	1	0	-0.501692	5.314430	2.832072
97	1	0	-1.889244	6.130978	0.931570
98	1	0	-1.264747	5.559366	-1.394146

Free Energy and Geometry for S-120 (Conformer 5 of 5):



Sum of electronic and thermal free energies: -2450.031750 a.u.

Number of imaginary frequencies: 0

Center Number	Atomic Number	Atomic Type	Coordinates (Angstroms) X	Y	Z
1	6	0	6.580589	1.346350	0.055019
2	6	0	7.956037	1.495158	0.241287
3	6	0	8.703428	0.402802	0.689994
4	6	0	8.053285	-0.808549	0.942403
5	6	0	6.678863	-0.954028	0.752469
6	6	0	5.911168	0.140647	0.294350
7	6	0	6.054682	-2.312904	1.022276
8	6	0	4.526690	-2.275548	1.126025
9	6	0	3.939723	-1.445555	-0.023061
10	6	0	4.393499	0.027517	0.127997
11	6	0	2.408988	-1.502149	-0.103610
12	6	0	1.799876	-0.670384	-1.274541
13	6	0	2.269970	0.791965	-1.100640
14	6	0	3.806609	0.902223	-0.999979
15	6	0	0.250355	-1.020501	-1.124087
16	6	0	0.282450	-2.521236	-0.664753
17	6	0	1.725010	-2.869449	-0.226420
18	8	0	10.052904	0.415621	0.913782
19	6	0	10.755737	1.623036	0.675257
20	1	0	3.936322	0.387552	1.067771

21	1	0	4.361844	-1.843904	-0.957990
22	1	0	2.045662	-1.044422	0.832648
23	6	0	2.270501	-1.209401	-2.649631
24	8	0	-0.496390	-1.030368	-2.339530
25	6	0	-0.540035	0.107895	-3.209064
26	6	0	-0.480167	-0.135051	-0.023322
27	6	0	-0.754628	1.242665	-0.446377
28	6	0	-1.746365	-0.727742	0.576758
29	6	0	-1.934702	-0.894405	1.958297
30	7	0	-3.225997	-1.413354	2.166005
31	6	0	-3.831596	-1.576495	0.937683
32	6	0	-2.941080	-1.152991	-0.048195
33	6	0	-1.129495	-0.651728	3.099018
34	6	0	-1.609956	-0.915345	4.355954
35	6	0	-2.925729	-1.436229	4.518004
36	6	0	-3.711021	-1.676110	3.430135
37	6	0	-1.057595	2.376540	-0.746863
38	6	0	-3.263287	-1.140521	-1.509720
39	6	0	-5.247974	-2.000773	0.835778
40	9	0	-5.654700	-2.090264	-0.440269
41	9	0	-5.475681	-3.203157	1.429425
42	9	0	-6.083962	-1.123992	1.467673
43	8	0	-3.515963	-0.135353	-2.143275
44	8	0	-3.286116	-2.383181	-2.010303
45	6	0	-3.599040	-2.497579	-3.418914
46	6	0	-3.684377	-3.976691	-3.743324
47	6	0	-1.259934	3.689532	-1.332673
48	8	0	-0.466796	4.123192	-2.167448
49	7	0	-2.359698	4.411891	-0.917451
50	6	0	-3.288016	3.971276	0.077195
51	6	0	-2.503203	5.761126	-1.468439
52	6	0	-3.571376	4.807668	1.165687
53	6	0	-4.502530	4.417193	2.127110
54	6	0	-5.147535	3.184150	2.018995
55	6	0	-4.865041	2.350583	0.935328
56	6	0	-3.951383	2.742801	-0.044224
57	1	0	6.022650	2.212438	-0.286672
58	1	0	8.421042	2.453042	0.037459
59	1	0	8.650425	-1.645960	1.294662
60	1	0	6.336228	-2.996381	0.206685
61	1	0	6.490349	-2.742899	1.933150
62	1	0	4.134905	-3.299455	1.111844
63	1	0	4.222177	-1.833367	2.086290
64	1	0	1.921314	1.432925	-1.917163
65	1	0	1.842672	1.217451	-0.184486
66	1	0	4.048726	1.956431	-0.826978
67	1	0	4.279149	0.635220	-1.953852
68	1	0	-0.425795	-2.690973	0.148586
69	1	0	-0.059252	-3.130747	-1.504208
70	1	0	2.231804	-3.486136	-0.978323
71	1	0	1.742747	-3.435342	0.710723
72	1	0	11.800959	1.414248	0.911933
73	1	0	10.678524	1.936780	-0.374567

74	1	0	10.394858	2.436566	1.319102
75	1	0	1.968136	-0.534794	-3.454543
76	1	0	3.358513	-1.294942	-2.697902
77	1	0	1.848568	-2.191401	-2.876717
78	1	0	0.192515	0.873290	-2.954145
79	1	0	-0.338220	-0.255214	-4.224147
80	1	0	-1.537229	0.552561	-3.177472
81	1	0	0.236306	-0.067480	0.805032
82	1	0	-0.132914	-0.247158	2.958548
83	1	0	-0.993700	-0.726392	5.228847
84	1	0	-3.320616	-1.649718	5.504944
85	1	0	-4.713654	-2.075584	3.486264
86	1	0	-4.541118	-1.975773	-3.613011
87	1	0	-2.808862	-1.997435	-3.986432
88	1	0	-3.916869	-4.110832	-4.805441
89	1	0	-2.734389	-4.477662	-3.531936
90	1	0	-4.469589	-4.460882	-3.153955
91	1	0	-3.559640	6.036385	-1.459665
92	1	0	-1.931869	6.501179	-0.893334
93	1	0	-2.122180	5.761278	-2.490269
94	1	0	-3.055261	5.758435	1.261998
95	1	0	-4.714830	5.075048	2.965830
96	1	0	-5.869128	2.877179	2.771224
97	1	0	-5.364506	1.390204	0.844584
98	1	0	-3.757280	2.095732	-0.893160

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