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Photochemistry

Enhancing Flavins Photochemical Activity in Hydrogen Atom Abstraction and Triplet Sensitization through Ring-Contraction

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Abstract: The isoalloxazine heterocycle of flavin cofactors reacts with various nucleophiles to form covalent adducts with important functions in enzymes. Molecular flavin models allow for the characterization of such adducts and the study of their properties. A fascinating set of reactions occurs when flavins react with hydroxide base, which leads to imidazolonequinoxalines, ring-contracted flavins, with so far unexplored activity. We report a systematic study of the photophysical properties of this new chromophore by absorption and emission spectroscopy as well as cyclic voltammetry. Excited, ring-contracted flavins are significantly stronger hydrogen atom abstractors when compared to the parent flavins, which allowed the direct trifluoromethylthiolation of aliphatic methine positions (bond dissociation energy (BDE) of 400.8 kJ mol^{-1}). In an orthogonal activity, their increased triplet energy ($E(S_0 \leftarrow T_1) =$ 244 kJ mol^{-1}) made sensitized reactions possible which exceeded the power of standard flavins. Combining both properties, ring-contracted flavin catalysts enabled the one-pot, five-step transformation of α-tropolone into *trans*-3,4-disubstituted cyclopentanones. We envision this new class of flavin-derived chromophores to open up new modes of reactivity that are currently impossible with unmodified flavins.

Introduction

The reaction of flavin mononucleotide (FMN) and flavin adenine dinucleotide (FAD) cofactors with nucleophiles leads to covalent adducts. The exact reaction position depends on the hard or soft nature of the nucleophile, and also the steric properties of surrounding substituents. Covalent adducts play a vital role in flavoenzyme-mediated catalytic reactions (Figure 1A).[1,2] The C4a-hydroperoxides **1** are formed by reductive activation of O_2 from air and are the central cornerstone of oxygenating activity under aerobic conditions.[3] In recent years, these adducts have been structurally expanded by the observation of similar N5-hydroperoxides by the groups of *Teufel* and *Moore*.[4] Covalent carbon-sulfur bonds, reversibly formed between the C4a-position and a cysteine thiol group (**2**), are key intermediates in light, oxygen, and voltage (LOV) photoreceptors.[5] With sulfites, covalent adducts are formed

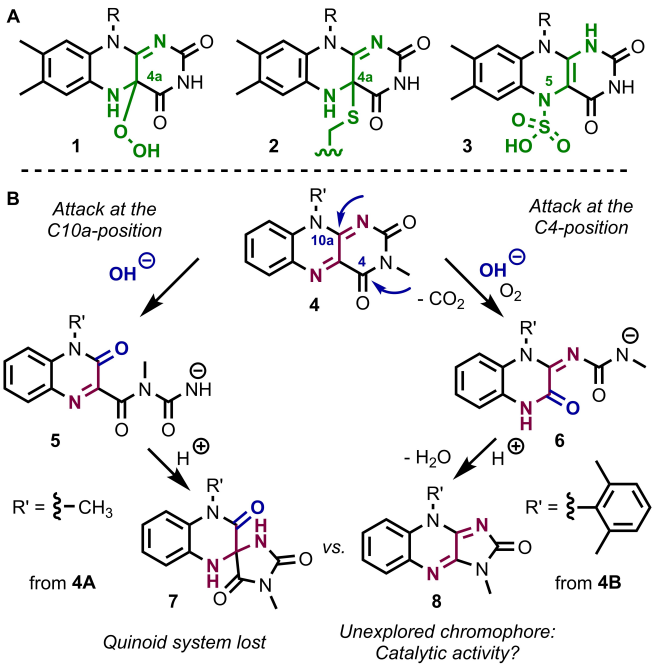

Figure 1. Covalent adducts of flavins with nucleophiles. A) Reversible formation of covalent adducts is an essential step in flavoenzymatic mechanisms. B) The reaction of molecular flavins with hydroxide nucleophiles proceeds via divergent pathways depending on the initial position of attack. R = Ribityl-ADP (FAD). ADP = Adenosine diphosphate.

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at the N5-position (**3**) and are central as intermediates for forming mixed anhydrides.[6] Carbanions also preferentially attack the N5-position, which is the pivotal first step in nitroalkane oxidation by *amino acid oxidases*.[7]

The importance of covalent adducts with the isoalloxazine core has prompted a series of synthetic studies, which aimed to elucidate the reactivity of different heterocycle positions towards incoming nucleophiles in the organic laboratory. *Bruice* and *Yoneda* investigated the reaction of simple isoalloxazines (**4**) with strong bases.[8] When exposed to hydroxide nucleophiles,[9] the authors identified two sites of initial bond formation, namely C4 and C10a (Figure 1B). Both pathways lead to a heterocycle ring-opening and either the formation of quinoxalinone **5** or **6**, respectively. The relative tendency of hydroxide attack to either position was found to be dependent on the steric effect of the R'-substituent. With a sterically demanding 2,6-xylyl substituent (from flavin **4B**), the C10a-position was found to be blocked, and the addition at the C4-position dominated. Both intermediates underwent irreversible C–N bond formation. In the case of quinoxalinone **5**, this led to spirohydantoin **7**, which does not possess a quinoid system and, therefore, does not resemble a flavin analogue anymore. On the other hand, quinoxalinone **6** cyclized to imidazolonequinoxaline **8**, which still contains the flavin-type quinoid system. No studies regarding the properties and catalytic activity of this compound class have been reported so far.

We aimed to systematically study the ring-contraction reaction with modified flavin catalysts and to investigate their photophysical properties. With these results in hand, we were interested in their ability to participate in catalytic transformations.[10,11] Novel redox-active organic compounds are also interesting regarding their application for energy storage in batteries.[12]

Results and Discussion

Synthesis and Spectroscopic Characterization

Building on the initial reports by *Bruice* and *Yoneda*, isoalloxazine **9** was first treated with lithium hydroxide, and imidazolonequinoxaline **10** was obtained (Figure 2). As expected, this reaction was found to be very unselective, and several reaction products were observed. The ring-contracted flavin **10** could be isolated albeit in a low yield of only 18%. Interestingly, the analogous reaction was much cleaner with the C6-CO_2Me (**11**) and C6-C(O)NHMe (**12**) derivatives,[13] resulting in ring-contracted flavins **13** (42%) and **14** (37%). We rationalized this improvement with increased reactivity of the C4-position towards hydroxide nucleophiles in flavins with electron-withdrawing substituents. The ring-contraction of flavin **11** occurred concomitant to saponification, and carboxylic acid **13** was isolated. The solid-state structure of **13** was elucidated directly from the powder sample by continuous rotation 3D electron diffraction (3D ED, Figure 2 top right).[14] The bulk product of **13** consisted of two isostructural polymorphs confirmed via both complementary techniques, *viz*. 3D ED and X-ray

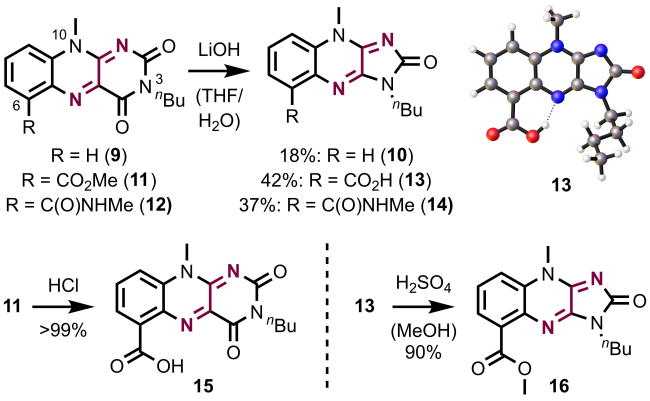


Figure 2. Ring-contraction of flavins under basic reaction conditions. Top right: ED structure of ring-contracted flavin **13** in the solid state (see the Supporting Information for details).

powder diffraction (see the Supporting Information for details).[15] In order to have a complete set of flavins and their ring-contracted analogs available, ester cleavage of flavin **11** was performed under acidic conditions yielding flavin **15**,[16] and the esterification of ring-contracted flavin **13** with methanol gave ester **16**. This set of synthetic procedures led to flavins and ring-contracted flavins with the following substituents in the C6-position: H, C(O)NHMe, CO_2Me, and CO_2H.

The redox potentials of ring-contracted flavins were then determined by cyclic voltammetry. In the ground state, N3,N10-dialkyl flavins (isoalloxazines) are weak oxidants with $E_{1/2} = -0.83$ V vs. SCE (CH_3CN).[17] The analogous ring-contracted flavin **10** has a significantly more negative redox potential of $E_{1/2} = -1.68$ V vs. SCE (CH_3CN). In other words, the imidazolonequinoxalines are less oxidizing in the ground state, which can be explained by the missing carbonyl group (Figure 3A). The carboxylic ester substituent in ring-contracted flavin **16** (Figure 3B) slightly moves the

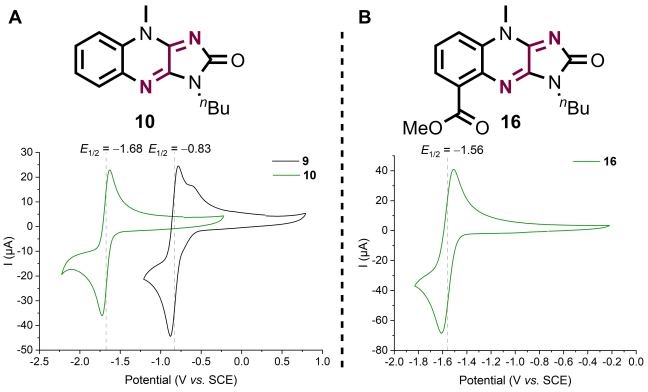


Figure 3. Comparison study of flavins and ring-contracted analogs by cyclic voltammetry. The unsubstituted core structures **9** and **10** are shown (A), and also ester-substituted ring-contracted flavin **16** (B). All data were recorded in acetonitrile solution with tetra-*n*-butylammonium hexafluorophosphate ($TBAPF_6$) as the electrolyte (see the Supporting Information for details).

redox potential back toward the positive direction with a value of $E_{1/2} = -1.56$ V vs. SCE (CH_3CN).

All ring-contracted flavins are colorless solids, which sets them apart from the intensively yellow-colored parent flavins.[18] The naturally occurring (–)-riboflavin has an absorption maximum at $\lambda = 443$ nm (EtOH solution). In contrast, both ring-contracted flavins **10** (Figure 4A) and **16** (Figure 4B) have similarly shaped absorption spectra with maxima at $\lambda = 352$ nm (**10**) and $\lambda = 347$ nm (**16**), which explains their appearance. Both compounds show fluorescence emission at $\lambda_{max} = 395$ nm. When determined from the intersection of absorption and emission spectra, both compounds have a similar singlet excited state energy of $E(S_0 \leftarrow S_1) = 319\ kJ\,mol^{-1}$, which is significantly higher compared to (–)-riboflavin ($E(S_0 \leftarrow S_1) = 244\ kJ\,mol^{-1}$).[18] Both compounds are relatively strong oxidants in the photochemically excited singlet state ($E^* = 1.63$ V (**10**) and 1.75 V (**16**) vs. SCE). The phosphorescence signals of ring-contracted flavins **10** and **16** were resolved by measuring the two compounds in a saturated solution of potassium iodide in ethanol,[19] which led to $E(S_0 \leftarrow T_1) = 244\ kJ\,mol^{-1}$ when measured at 77 K in both cases (see the Supporting Information for details). Again, this value is significantly higher compared to (–)-riboflavin ($E(S_0 \leftarrow T_1) = 205\ kJ\,mol^{-1}$).[18,20]

In addition to these photophysical characteristics, we probed for the activity of ring-contracted flavins as hydrogen atom abstractors in the excited state.[21] Model substrate **17** was chosen, which has a methine position (marked in red) with a relatively high bond dissociation energy (BDE) of 400.8 kJ mol^{-1} (for CH_3-CH_2-C<u>H</u>$(CH_3)_2$).[22] Indeed, deuteration of this methine position occurred and **17**-d was detected when irradiating a solution of substrate **17** and a catalytic amount of ring-contracted flavin **16** in a mixture of D_2O and CD_3CN (Figure 5). This result was observed by ^2H NMR (see the Supporting Information for details).[23] No deuteration occurred under analogous conditions when flavin **11** was used as the catalyst. Evidence for a reaction between excited flavin **16** and substrate **17** was also obtained by a *Stern–Volmer* quenching study (see the Supporting Information for details).

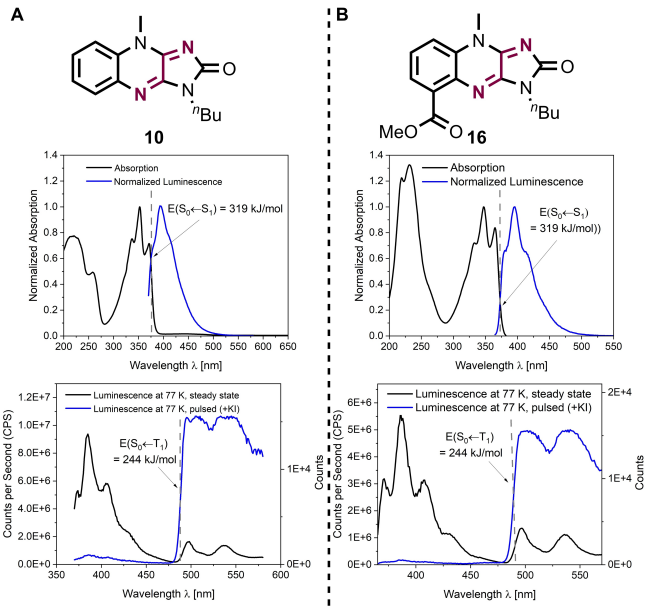


Figure 4. Spectroscopic characterization of ring-contracted flavins **10** (A) and **16** (B). Absorption and luminescence spectra (excitation at $\lambda = 365$ nm) were recorded in ethanol (80 μM solution). The phosphorescence spectra (50 μs delay) were recorded in a solution of saturated potassium iodide in ethanol at 77 K.

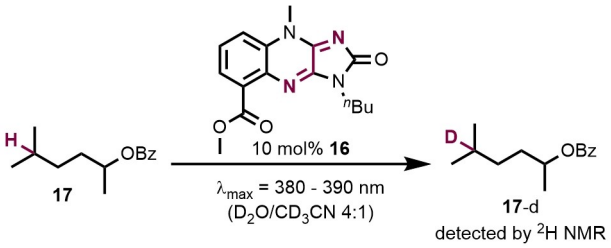


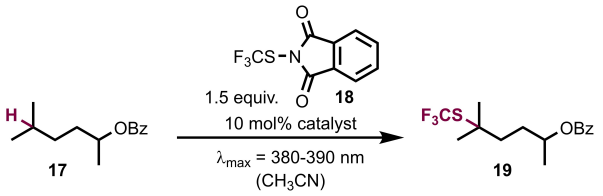
Figure 5. Deuteration experiment with ring-contracted flavin **16** as hydrogen atom abstractor in the excited state. The irradiation (50 mM with respect to **17**) was performed at room temperature for 16 h.

Catalytic Applications

The activity of ring-contracted flavin **16** in hydrogen atom abstraction led us to commence the catalytic studies with a reaction that initially requires this elementary step. The trifluoromethylthiolation[24,25] of organic molecules is of particular interest in pharmaceutical chemistry due to the high hydrophobicity (*Hansch* parameter of $\pi = 1.44$ vs. CF_3: $\pi = 0.88$) and electron withdrawing properties (*Hammett* parameter $\sigma_p = 0.50$ vs. CF_3: $\sigma_p = 0.54$) of the SCF_3-group.[26] The trifluoromethylthiolation of substrate **17** with *N*-(trifluoromethylthio)phthalimide[27] **18** was studied by *Glorius* and requires an oxidizing iridium photocatalyst $[Ir(dF(CF_3)ppy)_2(dtbbpy)]PF_6$ together with a hydrogen atom abstraction catalyst such as benzoate.[28] We wondered whether ring-contracted flavins would combine both catalytic activities (Table 1). An initial series of experiments revealed that the usual isoalloxazine-based flavins are incapable of mediating the reaction independent of irradiation wavelength and additional base (entries 1–3). Formation of thioether product **19** was observed when tetra-*n*-butylammonium benzoate ($BzONBu_4$) was added, albeit in a low yield of 18% (entries 4 and 5). It was concluded that excited flavins serve as oxidants for benzoate which in turn abstracts a hydrogen atom from substrate **17**. However, excited flavins themselves are incapable of mediating the reaction.

Indeed, switching to ring-contracted flavins led to product formation without any additive, consistent with a stronger hydrogen atom abstraction strength (entries 6–9). Only low levels of thioether **19** were formed with the carboxylic acid-containing catalyst **13**, while the unmodified ring-contracted flavin **10** was completely inactive. Catalyst

Table 1: The catalytic trifluoromethylthiolation mediated by flavins.



Entry	Catalyst with Substitution	Wavelength	Additive[a]	Yield[b]
1	Flavin **15** CO_2H	451 nm	–	n.d.
2	Flavin **11** CO_2Me	451 nm	–	n.d.
3	Flavin **11** CO_2Me	451 nm[c]	K_3PO_4	n.d.
4	Flavin **15** CO_2H	451 nm	$BzONBu_4$	18%
5	Flavin **15** CO_2H	451 nm	K_3PO_4	n.d.
6	Contracted **13** CO_2H	380–390 nm	–	10%
7	Contracted **10** H	380–390 nm	–	n.d.
8	Contracted **14** C(O)NHMe	380–390 nm	–	35%
9	Contracted **16** CO_2Me	380–390 nm	–	43%[d]
10	Contracted **13** CO_2H	380–390 nm	K_3PO_4	45%
11	Contracted **16** CO_2Me	380–390 nm	K_3PO_4	88%
12	TBADT	380–390 nm	K_3PO_4	19%
13	Benzophenone	365 nm	K_3PO_4	3%

All reactions were run for 16 h at room temperature. [a] Applied in a quantity of 5 mol%. [b] Yields were determined by NMR spectroscopy versus the internal standard trimethyl 1,3,5-benzenetricarboxylate. [c] Irradiation at 380–390 nm led to unchanged results. [d] The analogous experiment without catalyst resulted in no product formation. n.d. = No product was detected.

variants with amide (**14**) and ester (**16**) substituents led to improved results of 35% and 43% yield, respectively. The addition of potassium phosphate base improved the results significantly and an optimal yield of 88% was obtained with ring-contracted flavin **16** (entries 10 and 11). The acetonitrile solvent and an LED light source of 380–390 nm resulted from an extended screening for reaction conditions (see the Supporting Information for details). The established hydrogen atom abstraction photocatalysts tetra-*n*-butylammonium decatungstate (TBADT) and benzophenone only led to poor levels of product formation (entries 12 and 13).

The catalytic trifluoromethylthiolation with ring-contracted flavins is not limited to model substrate **17**, and ester substituents with cyclopropyl (**20**), thiophenyl (**21**), and pyridyl (**22**) groups are well-tolerated (Figure 6A). Based on the deuteration experiment (*cf.* Figure 5), selective hydrogen atom abstraction from the methine position by excited ring-contracted flavin **16*** is the plausible first step. Subsequent reaction of carbon-centred radical **23** with SCF_3-reagent **18** leads to the formation of thioether product **19**. The latter step releases a phthalimidyl radical, which likely regenerates the ring-contracted flavin **16**.[28,29] This photochemically excited catalyst **16*** was also successful in abstracting a hydrogen atom from aromatic aldehydes (see the Supporting Information for a *Stern–Volmer* quenching study), and allowed converting benzaldehyde derivative **24** into thioester **25** (Figure 6B).[30] Trapping adduct **26** was detected when the photochemical reaction was conducted in the presence of the persistent radical TEMPO, which corroborates the

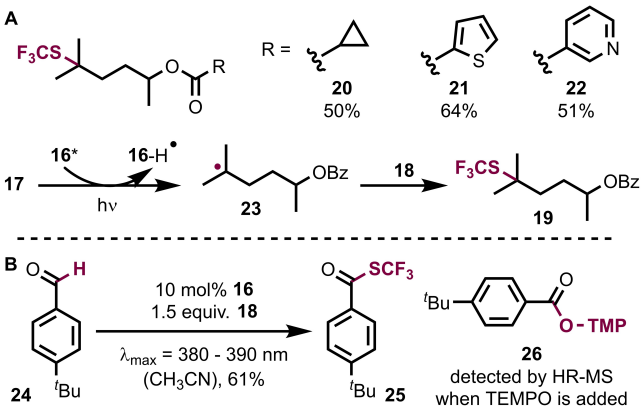


Figure 6. Application of ring-contracted flavin **16** in catalytic reactions. A) Trifluoromethylthiolation of the methine position in different substrates (conditions analogous to Table 1, entry 11). B) Catalytic conversion of aromatic aldehyde **24** into thioester **25**. All yields refer to isolated material. TMP: 2,2,6,6-Tetramethylpiperidinyl.

intermediate formation of acyl radicals by hydrogen atom abstraction.

The sensitization activity of ring-contracted flavins was then studied based on their significantly increased triplet energy E_T (*cf.* Figure 4).[31] Cycloheptadiene (**27**) seemed a suitable model substrate for probing reactivity differences between flavins and their ring-contracted analogues since its triplet energy E_T(**27**) = 228 kJ mol^{-1} lies between that of the two catalysts.[32] It was already shown that ester-modified flavin **11** is cleanly converted into the covalent adduct **28** by photochemical excitation (Figure 7A).[13] When an excess of cycloheptadiene was used, the remaining material stayed untouched during irradiation. In stark contrast, ring-con-

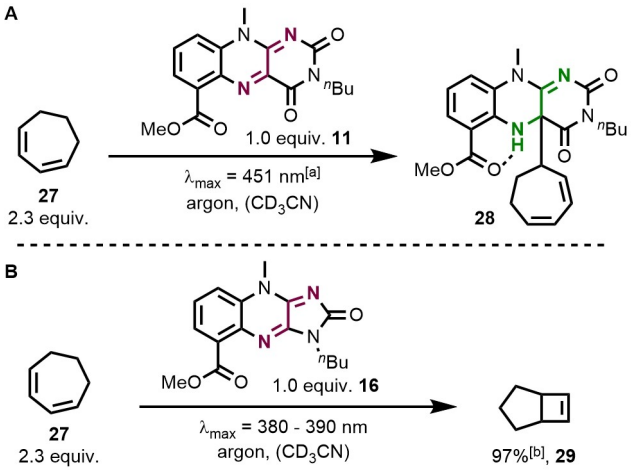


Figure 7. Comparison of flavin reactivity and their ring-contracted analogs towards cycloheptadiene (**27**). The substrate is not converted by irradiation without a catalyst at either λ_{max} = 380–390 nm or λ_{max} = 451 nm. [a] No conversion was observed when an LED of λ_{max} = 380–390 nm was used. [b] This is a volatile product and the yield was determined by NMR spectroscopy versus the internal standard trimethyl 1,3,5-benzenetricarboxylate.

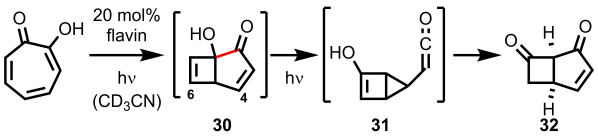
tracted flavin **16** acted as a triplet sensitizer under analogous conditions, and the clean formation of bicycloheptene **29** was observed (Figure 7B). This reaction was rationalized by a triplet-sensitized *E*/*Z*-isomerization of cycloheptadiene followed by a rapid, thermal cyclization to bicycloheptene **29**, and highlights the divergent reactivity between flavins and their ring-contracted analogues.[33]

Driven by the aim to apply ring-contracted flavins in a sequential multi-step reaction that combines both activities, namely energy transfer and hydrogen atom abstraction, α-tropolones were chosen as substrates (Table 2).[34] The electrocyclisation of α-tropolone methyl ethers[35] has attracted widespread attention and found several applications in total synthesis.[36] On the other hand, free α-tropolone was studied much less, although an early report by *Day* describes the formation of photoproducts **30** and **32** by direct excitation.[37] With careful control of the reaction conditions, intermediate **30** can be obtained by direct excitation at 300 nm,[38] but preparative synthesis and further applications of final product **32** (formed via its enol tautomer) are elusive. When α-tropolone was irradiated at λ_{max} = 380–390 nm, product **32** was not accumulated in significant quantities and decomposition dominated (entry 1). The reaction proceeded much cleaner in the presence of flavin **11**. However, the predominant formation of intermediate **30** occurred at λ_{max} = 380–390 nm, while λ_{max} = 451 nm was ineffective (entries 2 and 3). In contrast, ring-contracted flavin **16** provided cyclopentenone **32** in good efficiency with 86 % yield (entry 4). In the presence of piperylene as a triplet quencher,[39] the formation of cyclopentenone **32** was significantly suppressed. A diminished yield of only 44 % was observed, while the overall mass balance was still good (entry 5).

Based on seminal work by *Day* and *Chapman* on tropolone photochemistry,[40] the following mechanistic rationale is plausible for explaining the results. A 4π-electrocyclization of α-tropolone to cyclobutene **30** is triggered by direct irradiation at λ_{max} = 380–390 nm (α-tropolone absorption at λ_{max} = 354 nm).[41] However, this primary photoproduct is unstable under the reaction conditions, and the second photochemical step seems inefficient under direct irradiation at this wavelength. The subsequent reaction of intermediate **30** to cyclopropyl ketene **31** resembles an initial α-cleavage (C–C bond marked in red) of the photochemically excited enone and a subsequent C–C bond formation between positions C4 and C6.[42] The α-cleavage of cyclopentenones and the formation of cyclopropyl ketenes are well-studied, and it has been shown that these reactions can proceed on the triplet hypersurface, which opens up the possibility of using a triplet sensitizer.[43] Therefore, the improved reactivity with flavin **16** is likely explained by triplet sensitization of this second photochemical step, which rapidly converts intermediate **30** into **32**. Sensitization is more efficient with a ring-contracted flavin due to its higher triplet energy, and this second photochemical reaction is suppressed by the triplet quencher piperylene. Consistent with this analysis, the first photochemical step of the reaction sequence is not affected by the added piperylene (see entries 6 to 8 after only 15 min irradiation time). The final conversion of cyclopropyl ketene **31** to cyclopentenone **32** is a thermal reaction that resembles the well-studied isomerization of this substrate class.[44] Careful monitoring of the photochemical reaction in intervals of 15 min corroborated the improved activity of ring-contracted flavin **16** (see the Supporting Information for details).

The three-step α-tropolone photoreaction was then embedded into a one-pot reaction sequence mediated by ring-contracted flavin **16**. Based on the successful hydrogen atom abstraction with aromatic aldehyde substrates (*cf.* Figure 6B), we aimed to add acyl radicals, analogously generated by flavin-mediated hydrogen atom abstraction, to the cyclopentenone part of bicyclic photoproduct **32**.[45] Indeed, when a mixture of aromatic aldehyde **24** and α-tropolone was irradiated in the presence of ring-contracted flavin **16**, the formation of triketone **33** was identified in the crude mixture (Figure 8). However, its high

Table 2: Three-step cyclization of unsubstituted α-tropolone.



30 **31** **32**

Entry	Catalyst	Wavelength[a]	Tropolone[b]	**30**[b]	**32**[b]
1	none	380–390 nm	–	–	9%
2	**11**	380–390 nm	8%	65%	18%
3	**11**	451 nm	>99%	–	–
4	**16**	380–390 nm	–	–	86%
5[c]	**16**	380–390 nm	2%	41%	44%
6[d]	none	380–390 nm	35%	28%	4%
7[d]	**16**	380–390 nm	67%	23%	5%
8[c,d]	**16**	380–390 nm	70%	27%	3%

All samples were irradiated for 105 min (unless noted otherwise) at room temperature under an atmosphere of argon. [a] Wavelength of the LED used for irradiation (λ_{max}). [b] Yields were determined by NMR spectroscopy versus the internal standard trimethyl 1,3,5-benzenetricarboxylate. [c] With 10 equiv. of piperylene. [d] Only 15 min of irradiation.

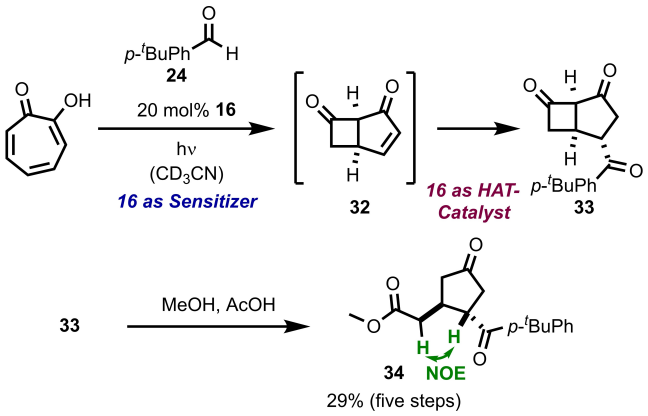


Figure 8. Sequential multi-step reaction leading to cyclopentanone **34**. The yield was determined with isolated material. It refers to the entire five-step sequence and is given with respect to α-tropolone.

reactivity made purification attempts unsuccessful. We therefore performed a subsequent methanolysis under acidic conditions, which led to a clean cyclobutane ring opening and *trans*-3,4-disubstituted cyclopentanone **34**. The latter was formed as a single diastereomer in 29 % yield, and the relative configuration was determined by NOE (nuclear *Overhauser* effect) contacts (see the Supporting Information for details).

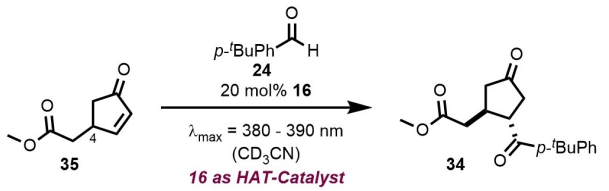
The α-tropolone was fully consumed during the reaction and no other side products were detected in the crude NMR spectrum. This observation was rationalized by the instability of the reactive photoproducts **30** and **32** under prolonged irradiation, leading to a diminished yield. Therefore, the order of reaction steps was switched. Methanolysis of photoproduct **32** to the more stable cyclopentenone **35** was performed first, followed by acyl radical addition. This reaction was initially probed with cyclopentenone material that was generated separately by the photochemical method (Table 3).[46]

However, cyclopentenone **35** was significantly less reactive towards radical addition when compared to bicycle **32**, and no product was formed initially (entry 1). Fortunately, the addition of *Lewis* acids could restore catalytic activity. While boron trifluoride and lithium chloride gave low to moderate yields (entries 2 and 3), the addition of one equivalent of zinc chloride resulted in 54 % yield of the corresponding *trans*-3,4-disubstituted cyclopentanone **34** (entry 4). The same stereoisomer was formed under these reaction conditions compared to the previous addition to bicycle **32** since the same enone face is blocked by the substituent in the 4-position.

With these conditions in hand, the entire one-pot reaction sequence was investigated (Figure 9). Photoproduct **32** was initially obtained within 105 min irradiation time (*cf.* Table 2) and methanolic acetic acid was then added to the reaction mixture. Methanolysis to cyclopentenone **35** was completed after three hours as indicated by TLC analysis. The crude solution was then combined with aldehyde **24** and zinc chloride, and again irradiated for 16 h. Under these conditions, the *trans*-3,4-disubstituted cyclopentanone **34** was isolated in a significantly improved yield of 52 %. No product formation was detected with benzophenone, xanthone, or $[Ir(dF(CF_3)ppy)_2(bpy)]PF_6$ catalysts in the analogous sequence,[47] while dominant substrate and catalyst decomposition was observed instead. This result highlights the stability and effectiveness of ring-contracted flavin **16**.

Different aldehyde reaction partners were then studied and we were pleased to see that the one-pot, five-step procedure worked for various substituted aromatic aldehydes (Figure 10). Both fluoro (**36**) and bromo (**37**) substituents gave similar or even higher yields compared to *tert*-butyl derivative **34**. Chloro substituents in *para* (**38**) and *meta* (**39**) position were also tolerated. This new method offers direct access to *trans*-3,4-disubstituted cyclopentanones from α-tropolone with several handles for further modifications.

Table 3: Acyl radical addition to cyclopentenone **35**.



Entry	Lewis Acid[a]	**34**[b]
1	none	–
2	$BF_3 \cdot OEt_2$	11 %
3	LiCl	40 %
4	$ZnCl_2$	54 %

Reactions were run for 16 h at room temperature. [a] One equivalent of the *Lewis* acid was used. [b] Yields were determined by NMR spectroscopy versus the internal standard trimethyl 1,3,5-benzenetricarboxylate.

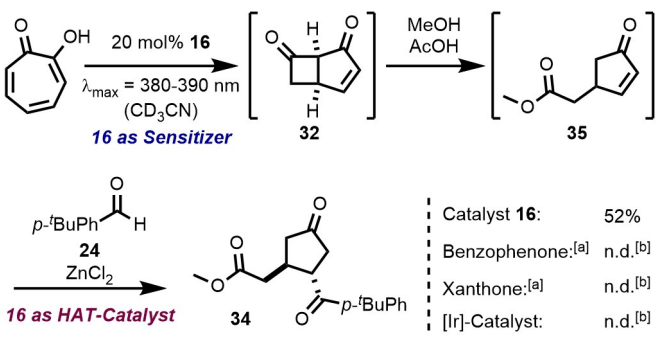


Figure 9. Sequential multi-step reaction leading to cyclopentanone **34**. The yield refers to isolated material and is given with respect to the α-tropolone starting material. [a] Either by irradiation at $\lambda_{max} = 365$ nm or $\lambda_{max} = 380–390$ nm. [b] No product formation was detected with these catalysts. [Ir]: $[Ir(dF(CF_3)ppy)_2(bpy)]PF_6$.

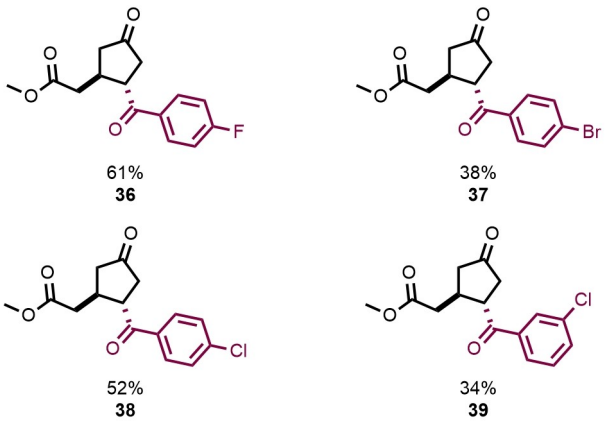


Figure 10. Reaction products of the five-step sequence. All yields refer to isolated material and are given with respect to the α-tropolone starting material.

Conclusion

Imidazolonequinoxalines were obtained from modified molecular flavins by a selective ring-contraction reaction under hydroxide basic conditions. The redox-active species maintain the crucial quinoid system and are characterized by a weaker oxidation strength in the ground state. In the photochemically excited state, they are significantly stronger hydrogen atom abstractors and display a higher triplet energy compared to their parent flavins. Catalytic applications for all increased activities are shown, and it is clear that ring-contracted flavins unlock reactivity which is otherwise inaccessible with flavins. By combining triplet sensitization and hydrogen atom abstraction, we developed a one-pot, five-step reaction sequence with ring-contracted flavins. From unsubstituted α-tropolone, this method allows direct access to *trans*-3,4-disubstituted cyclopentanones. We envision these new redox-active organic molecules to find various applications ranging from homogeneous catalysis to other fields such as energy storage.

Supporting Information

The data that support the findings of this study are available in the supplementary material of this article.

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Conflict of Interest

The authors declare no conflict of interest.

Data Availability Statement

The data that support the findings of this study are available in the supplementary material of this article.

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