

# ***Probing Diazo Compounds for Electro-Cascade Thiolation/Cyclization/Reduction Sequence***

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## **Abstract:**

Diazo compounds have extensively been investigated under light or metal-mediated conditions to carry out carbene-mediated transformations. In the search for novel reactivity, investigating these dinitrogen substrates under electrochemical conditions remained underexplored. Herein, we have explored diazo compounds under electrochemical conditions to establish a cascade sequence of thiolation/cyclization/reduction reactions. Electrolyzing styryl diazo imides and aryl thiols enables direct access to a single diastereoisomer of 2,5-pyrrolidine-dione-fused thiochromans in good yields under mild and metal-free conditions. Notably, a tunable reactivity was achieved via S-H insertion at the diazo center in slightly modified reaction conditions. Based on the experimental evidences, including the detection of key intermediates and computational studies, the mechanism for the electrochemical cascade reaction has also been established.

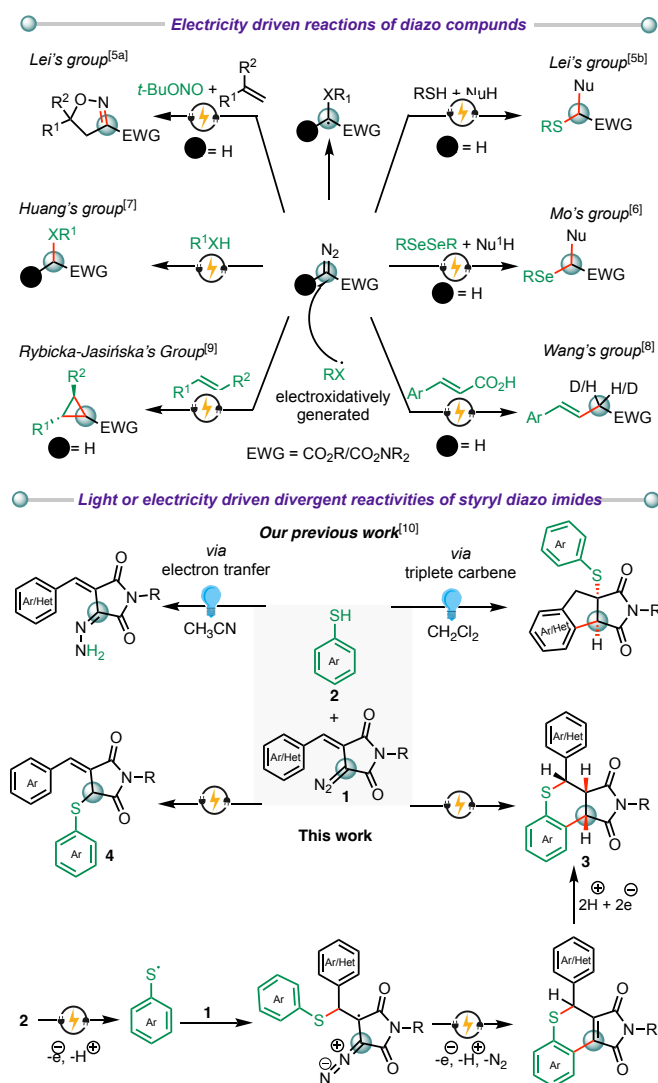
## Introduction

Diazo compounds have served as valuable precursors in organic synthesis *via* photochemical, thermal, or transition metal-mediated decomposition to carbenes/metal carbenoids. These reactive intermediates have generally been investigated for well-established Wolff rearrangement, X-H insertion, cyclopropanation, ylide formations, etc.<sup>1-9</sup> Beyond carbene reactivity, the diazo compounds display amphiphilic behaviour by serving as nucleophiles and electrophiles.<sup>10-16</sup> In addition, under high temperature, transition-metal mediated conditions, with stoichiometric strong oxidants or photoredox catalysis, the diazo functionality was found to serve as a radical acceptor to generate another radical at the same carbon from where the dinitrogen is eliminated.<sup>17-22</sup>

In the context of radical reactions, over the last few years, the electrochemical redox process has emerged as an excellent tool to develop not only a similar reactivity to that mediated by the oxidants/metal catalysis/corresponding photoredox catalysis but also open the gate for unusual reactions, which are otherwise not established.<sup>23-34</sup> Despite the massive potential of diazo compounds in organic synthesis and electro-organic synthesis being a sustainable approach, the applications of diazo compounds to explore new radical reactivity under electrolysis remain elusive. Lei and co-workers<sup>35-36</sup> were the first to establish the diazo compounds as a radical acceptor in electrochemical conditions to initiate the corresponding cascade sequences. The concept of electrolysis-assisted generation of radical species at the diazo carbon center was further explored by the research groups of Mo,<sup>37</sup> Huang,<sup>38</sup> and Wang<sup>39</sup> Alternatively, Rybicka-Jasińska and co-workers demonstrated the well-established formal [2 + 1] cycloaddition of diazo compounds with alkenes *via* radical cation intermediates under electrolysis.<sup>40</sup> In all these electrochemical strategies, the radical/radical cation intermediates generated at the anode add directly to the site of N<sub>2</sub> exclusion. Furthermore, these strategies are mainly alternatives to the existing established methods and mostly employ diazoacetates as substrates. We anticipated a huge scope for further development in the electrochemical reactions of diazo compounds, especially by going beyond the simpler diazo esters or amides and having diazo substrates having an additional reactive site along with the diazo functionality.

Recently our group disclosed an unusual solvent-controlled divergent reactions of styryl diazo imides **1** with thiols **2** under photochemical conditions to construct indane-fused pyrrolindiones *via* aryl C-H functionalization/thiolation sequence or reduction of diazo group to hydrazones.<sup>41</sup> In the former case, photolysis of diazo imide led to the generation of triplet carbene, which makes intramolecular C-C bond formation more facile to initially form a five-membered intermediate, which eventually undergoes diastereoselective C-S bond formation. We were intrigued to exploit the different reactivity of these diazo imides with aryl thiols under electrochemical conditions. Our idea was not only to have direct electrochemical C-S bond formation at the diazo center,<sup>36,38</sup> but to initiate a new electrochemical cascade sequence. It was envisioned that at the outset, electricity should assist the one-electron oxidation of thiol to thiyl radical<sup>42</sup> to allow initial C-S bond formation, contrary to the photochemical conditions. Further, it was realized that the anodically generated thiyl radical intermediate,

apart from adding to the diazo center, should undergo the addition to the C=C, leading to a cascade sequence, where one of the aromatic rings will undergo further cyclization at the diazo center. Such a reaction sequence is not only mechanistically distinct from that reported under light by using the same substrates,<sup>41</sup> but also leads to an entirely different class of heterocycles, *i.e.* pyrrolidine-2,5-dione-fused thiochromans.<sup>43-45</sup>



**Scheme 1.** Reactivities of diazo compounds under electrochemical conditions and divergency in the photo- vs electrochemical reactions of diazo imides.

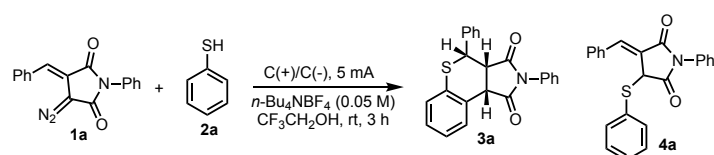
## Results

### Optimization Studies

Our efforts began with the electrolysis of cyclic diazo imide **1a** with thiophenol **2a** in an undivided cell (Table 1). After screening various solvents (entries 1-3) by using graphite electrodes and tetrabutylammonium tetrafluoroborate as an electrolyte at 5 mA current, 2,2,2-trifluoroethanol was found to be the best solvent providing the desired product **3a** as a single diastereoisomer in 78% yields (entry 3). Slightly increasing or decreasing the magnitude of the current led to a lower yield of product **3a**, whereas at 10 mA current, the product was not observed (entries 4-6). The reaction was found to be sensitive to temperature change as the desired

product was not observed at higher temperatures (entry 7). Varying electrolytes to *n*-Bu<sub>4</sub>NClO<sub>4</sub>, NaClO<sub>4</sub>, and NaCl did not help in improving the yield of **3a** (entries 8-10). Further, the change in electrode materials also turned out to be ineffective in increasing the product yields (entry 11). When the reaction was carried out without electricity, the product formation was not observed, which establishes the importance of current in the reaction. While slightly modifying the reaction conditions by using slightly different electrode materials, solvent, and excess thiophenol, **4a** as a major product was isolated in 64% yield *via* S-H insertion to the diazo carbon center (Table 1 entry 13 and see Table S1.1 for optimization leading to product **4a**).<sup>46</sup>

**Table 1:** Optimization studies

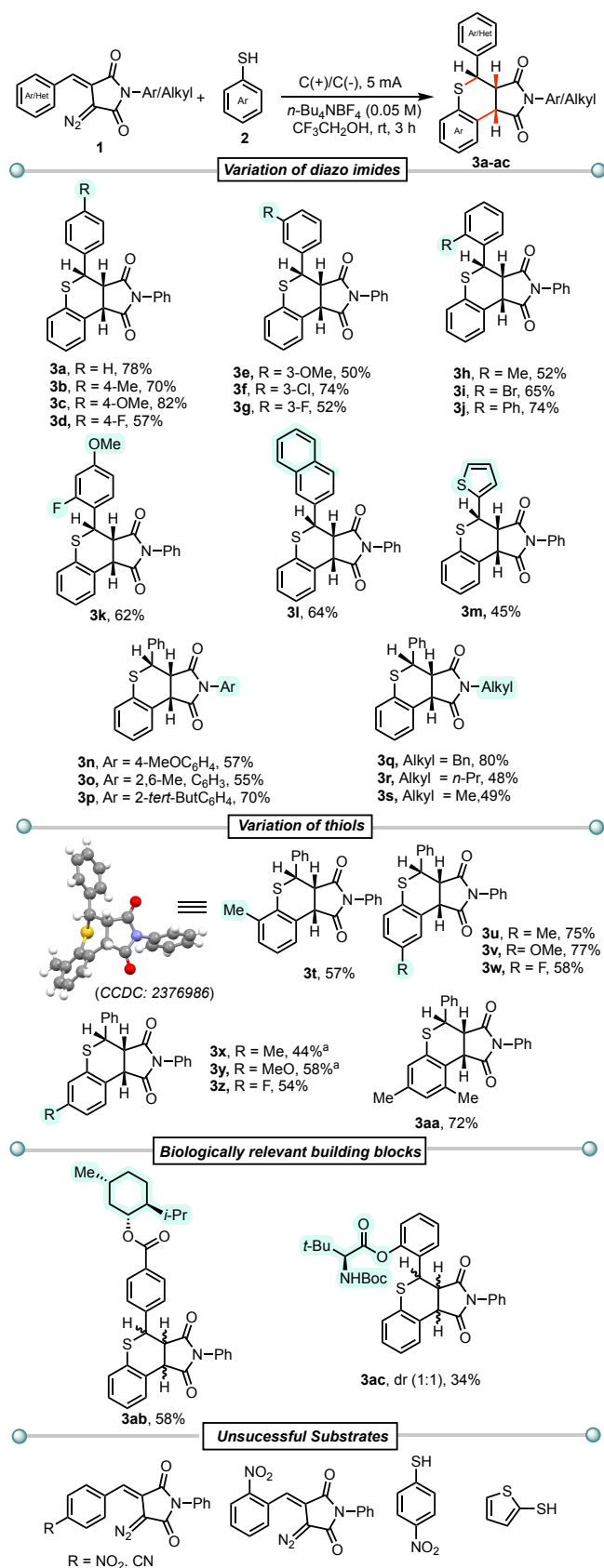


Entry	Deviation from standard conditions	3a/4a	Yield (%) <sup>b</sup>
1	MeOH as solvent	3a	50
2	EtOH, HFIP, DMA, DMSO as solvent	3a	ND
3	None	3a	78
4	Constant current @ 3 mA	3a	48
5	Constant current @ 8 mA	3a	25
6	Constant current @ 10 mA	3a	ND
7	At 50 °C and 70 °C	3a	ND
8	<i>n</i> -Bu <sub>4</sub> NClO <sub>4</sub> as electrolyte	3a	20
9	NaClO <sub>4</sub> as electrolyte	3a	ND
10	NaCl as electrolyte	3a	ND
11	C(+)/Pt(-) as electrode	3a	60
12	No electricity	3a	NR
13	5.0 eq. <b>2a</b> , MeOH, C(+)/Pt(-)	4a	64

Standard reaction conditions: **1a** (0.1 mmol), **2a** (0.1 mmol), *n*-Bu<sub>4</sub>NBF<sub>4</sub> (0.05 M), C(+)|C(-) as electrodes, current (5 mA) in CF<sub>3</sub>CH<sub>2</sub>OH (2.0 mL) at rt. Electrodes size (W x H x D): 8.0 mm x 52.5 mm x 2.0 mm. ND: not detected, NR: No Reaction. Yield refers to the isolated yield of products **3/4**.

### Substrate Scope Evaluation

After optimizing the reaction conditions for the electrochemical synthesis of pyrrolidinedione-fused thiochroman **3a** (Table 1, entry 3), we investigated the substrate scope and limitations by varying diazo imides and thiols (Scheme 2). Initially, the scope was investigated with different diazo imides. The *para*-substituted electron-rich (R = Me, OMe) diazo imides give products **3b** and **3c** in 70% and 82% yields. A 4-fluoro substituted substrate found to be compatible, however resulted in lower yield (57%) of **3d**. The reaction works well with *meta*-methoxy and -chloro substituted diazo imides to access **3e-f** in good yields; however, a *meta*-fluoro substituted substrate resulted in a diminished yield 54% of **3g**. The sterically crowded substrates *i.e.* *ortho*-substitution diazo imides were well tolerated for our electrochemical cascade sequence, yielding **3h-j** in 52-74% yields. In addition, the diazo imides bearing 2-F, 4-OMe phenyl and naphthyl groups also react without much difficulty to provide **3k** and **3l** in 62% and

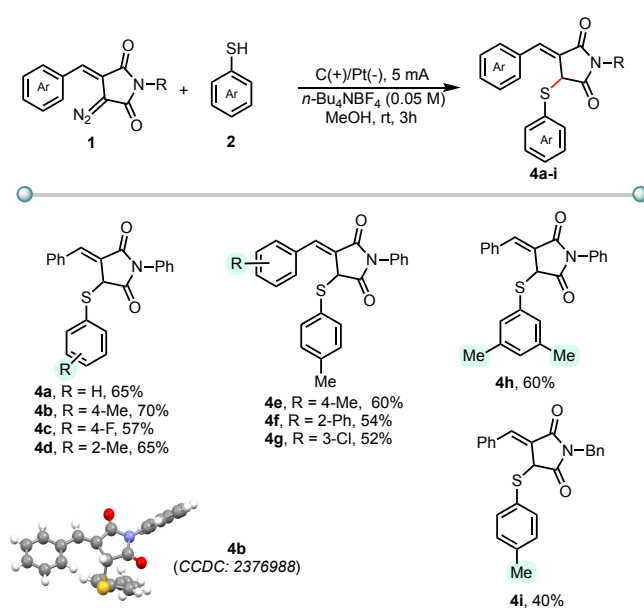


**Scheme 2.** Substrate scope for electrochemical thiolation/cyclization/reduction cascade sequence involving diazo imides. Reaction conditions: **1** (0.1 mmol), **2** (0.1 mmol), *n*-Bu<sub>4</sub>NBF<sub>4</sub> (0.05 M), C(+)|C(-) as electrodes, current (5 mA) in CF<sub>3</sub>CH<sub>2</sub>OH (2.0 mL) at rt. Electrodes size (W x H x D): 8.0 mm x 52.5 mm x 2.0 mm. ND = not detected. Yield refers to the isolated yield of products **3a-ac**. <sup>a</sup>Unidentified signals have been seen in <sup>1</sup>H NMR of the product in a 3:1 ratio.

64% yields, respectively. A thiophene-substituted diazo imide also provided the desired product **3m**, however, in a modest yield of 45%. The different *N*-aryl groups (Ar = 4-OMeC<sub>6</sub>H<sub>4</sub>, 2,6-Me<sub>2</sub>C<sub>6</sub>H<sub>3</sub> or 2-*tert* butylC<sub>6</sub>H<sub>4</sub>) fit well to the substrate scope providing desired products **3n-p** in acceptable yields. The *N*-benzyl and *N*-alkyl substitutions were also allowed, as the former provided **3q** in a higher yield of 80%, whereas the latter gave **3r-s** in moderate yields (48-49%). After screening diverse diazo imides, we pursued to examine the behaviour of different substituted thiophenols. The 2-Me, 4-Me, 4-OMe and 4-F substituted thiophenol derivatives provided thiochroman products **3t-w** in 57-78% yields. The reaction with *meta*-substituted thiophenols (R = 3-Me, 3-OMe) gives the products **3x-y**, but the products could not be completely purified due to unknown impurities in a 3:1 ratio (probably the diastereoisomers). Nonetheless, with 3-fluorothiophenol, only a single product, **3z** obtained a 55% yield. A disubstituted 3,5-dimethyl thiophenol gives product **3aa** in 72% yields.

The electro-cascade reaction occurs efficiently with the diazo imides bearing a natural product (Menthol), and amino acid (*L*-*tert*-Leucine) as side chain. The corresponding products **3ab-ac** were isolated in reasonable yields with no diastereo-differentiation. The limitation of the present method lies within the use of strongly electron-withdrawing groups (eg. -NO<sub>2</sub>/-CN) on the aryl ring of diazo imides and corresponding thiophenol derivative as well as thiophene-2-thiols, as the desired reaction failed in all these cases.

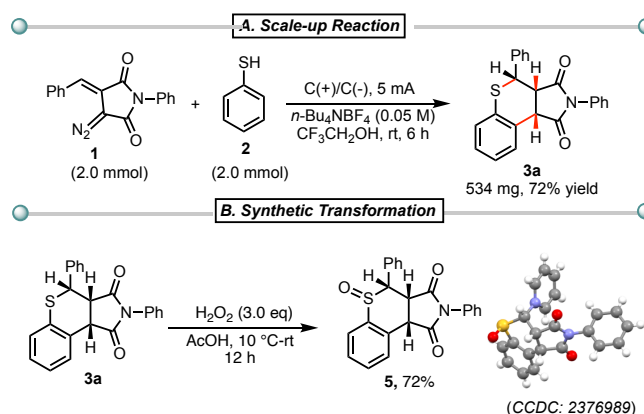
Further, the generality of direct S-H insertion to the diazo center was investigated to access the divergent class of products **4**. (Scheme 3). The reaction was found to be fairly general in terms of variation in the substituent on both aryl rings of diazo imides and aryl thiols to afford **4a-h** in 52-70% yields. The *N*-benzyl diazo imide also provided the desired product **4i**, however, in a lower yield of 40%.



**Scheme 3.** Substrate scope for S-H insertion of diazo imides. Reaction conditions: **1** (0.1 mmol), **2** (0.5 mmol), *n*-Bu<sub>4</sub>NBF<sub>4</sub> (0.05 M), C(+)|Pt(-) as electrodes, current (5 mA) in MeOH (2.0 mL) at rt. Electrodes size (W x H x D): 8.0 mm x 52.5 mm x 2.0 mm. ND = not detected. Yield refers to the isolated yield of products **4a-i**.

### Scale-Up Reaction and Synthetic Transformation

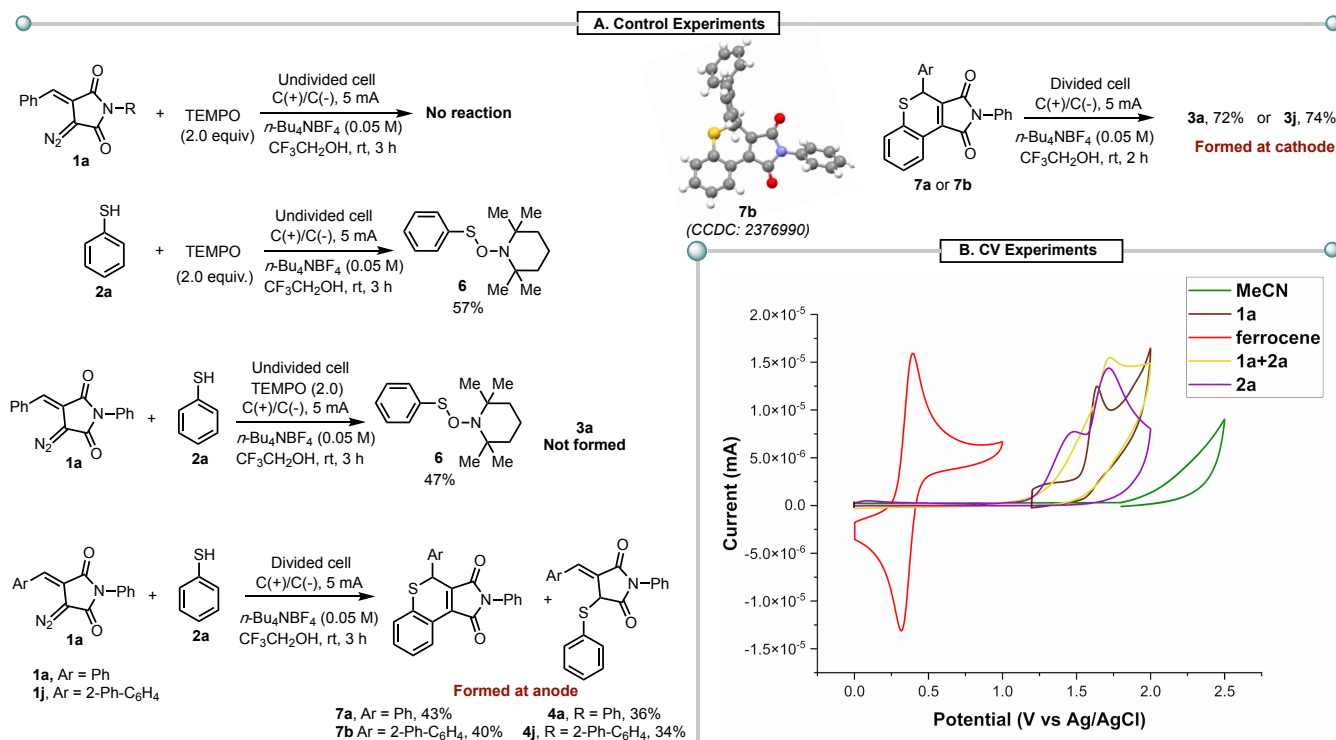
After evaluating the substrate scope/limitations of electro-cascade synthesis of pyrrolidinedione-fused thiochroman **3a**, a scale-up process was performed. The reaction worked with equal efficiency, without a significant loss in the yield, suggesting the practicability of the developed electrochemical process (Scheme 4A). Further, a synthetic application of the thiochroman product **3a** has been demonstrated by H<sub>2</sub>O<sub>2</sub>-AcOH mediated oxidation of sulfide to sulfoxide **5** in good yield (Scheme 4B).



**Scheme 4.** Scale-up reaction and a synthetic transformation.

### Mechanistic Investigations

In order to gain insight into the mechanism, various control experiments were carried out (Scheme 5A). The radical trapping studies suggested the generation of thiyl radical, as TEMPO trapped adduct **6** was isolated in the model reaction when carried out in the presence of TEMPO or by electrolyzing thiophenol with TEMPO. No such radical trapping was observed when the diazo imide **1a** and TEMPO were electrolyzed in the absence of thiophenol. Further, the CV experiments suggested that the anodic oxidation of thiol is more facile than that of diazo imide (Scheme 5B). The possibility of anodic oxidation as a key step to initiate the cascade reaction was also confirmed by performing two independent reactions at the anode in a divided cell, which gives the thiochromene products **7a** and **7b** along with the formation of **4a** and **4j** (Scheme 5A). It was contemplated that the thiochromene derivatives (**7a** and **7b**) could be the intermediate formed at the anode, which undergoes cathodic reduction of unsaturated C=C<sup>47-52</sup> to provide the desired product. As expected, adducts **7a** and **7b** both provided the product **3a** and **3j**, respectively, after cathodic reduction when the electrolysis was carried out in a divided cell. The detection of products **4a** and **4j** at the anode gives an indication that the S-H insertion process occurs only at the anode.

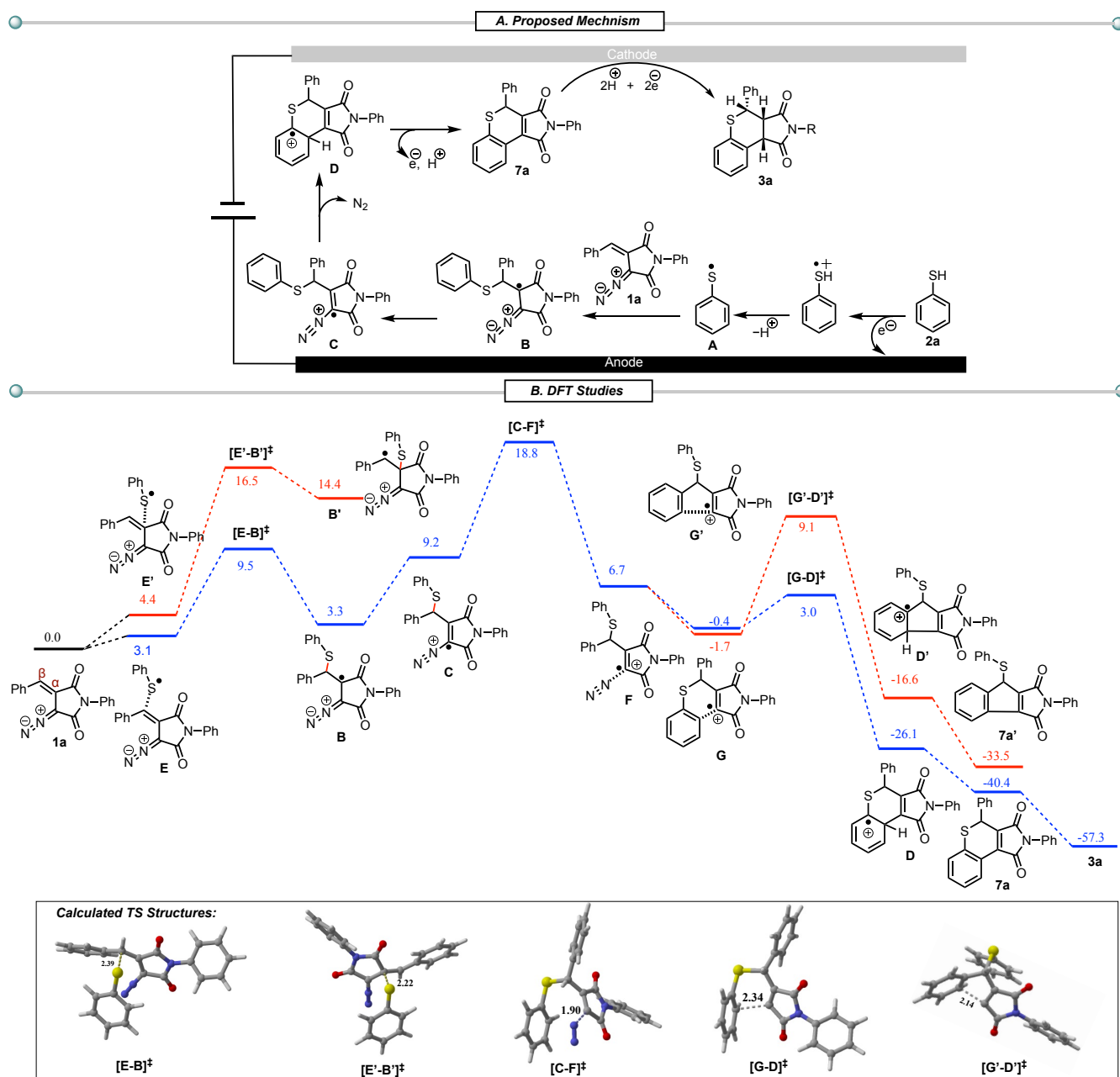


**Scheme 5.** Control experiments and CV studies.

To support the experimental findings and to further establish the chemo- and stereo-selective outcome of the electrochemical cascade sequence, we have carried out detailed density functional theory (DFT) computations. Scheme 6A depicts the proposed mechanism based on the experimental studies beginning from diazo imide **1a** with thiophenol (**2a**). The energetic features of this proposed mechanism can be understood by using the Gibbs free energy profile (Scheme 6B). Uptake of anodically generated thiyl radical (**A**) by diazo imide **1a** results in the formation of adducts **E** and **E'**. The addition of thiyl radical to  $\beta$ -carbon yields an intermediate **B** via transition state  $[\mathbf{E}-\mathbf{B}]^\ddagger$  whereas addition at  $\alpha$ -carbon results in benzylic radical **B'** via TS  $[\mathbf{E}'-\mathbf{B}']^\ddagger$  with the Gibbs free energies of 9.5 kcal/mol  $[\mathbf{E}-\mathbf{B}]^\ddagger$  and 16.5 kcal/mol  $[\mathbf{E}'-\mathbf{B}']^\ddagger$ , respectively. Comparison of the transition states indicates that the addition takes place at  $\beta$ -carbon of diazo imide **1a** due to the lower activation barrier (6.4 kcal/mol vs. 12.1 kcal/mol).<sup>53</sup> In the next step, the departure of the labile diazo group from intermediate **C** leads to the formation of an intermediate **F** via TS  $[\mathbf{C}-\mathbf{F}]^\ddagger$ , which can undergo an intramolecular nucleophilic attack either by the phenyl ring attached to the  $\beta$ -carbon or sulphur atom. Prior to this, an intermediate **F** undergoes a conformational change to generate lower energy intermediates **G** and **G'**. Intramolecular nucleophilic attack by the phenyl ring attached to the sulphur atom leads to the formation of an adduct **D** (six-membered) via TS  $[\mathbf{G}-\mathbf{D}]^\ddagger$  whereas an adduct **D'** (five-membered) is formed following an intramolecular nucleophilic attack by the phenyl ring attached at  $\beta$ -carbon via TS  $[\mathbf{G}'-\mathbf{D}']^\ddagger$ . The corresponding Gibbs free energies of these transition states are found to be 3.0 kcal/mol  $[\mathbf{G}-\mathbf{D}]^\ddagger$  and 9.1 kcal/mol  $[\mathbf{G}'-\mathbf{D}']^\ddagger$  respectively. A comparison of these transition states suggested the favourable formation of a six-membered ring as the activation barrier for the TS  $[\mathbf{G}-\mathbf{D}]^\ddagger$  is significantly lower (3.4 kcal/mol) than the  $[\mathbf{G}'-\mathbf{D}']^\ddagger$  (10.8 kcal/mol).<sup>54</sup> Subsequently, intermediate **D** undergoes single electron oxidation at the anode to generate a cation, which loses a proton to retain the aromaticity of the



phenyl ring, thereby leading to the formation of thiochromen intermediate **7a**. In the final step, an addition of two electrons and two protons at the cathode to an intermediate **7a** leads to the formation of final product **3a**. Finally, the relative configuration of the experimentally obtained product was found to be in agreement with the DFT computed product, as the former was found to be 2.0 kcal/mol lower than the diastereomeric product.



**Scheme 6.** Proposed mechanism based on experimental finding and DFT studies.

## Conclusions

In conclusion, we have developed an electrochemical cascade reaction by using diazo imides providing direct access to single diastereomers of 2,5-pyrrolidine-dione-fused thiochromans in good yields under mild conditions. In the limited known electrochemical synthesis involving diazo compounds, the addition of anodically generated

radical takes place to the diazo center. However, in the reaction of styryl diazo imides, the anodically generated thiyl radical species initially adds to the C=C to initiate the unique cascade sequence involving thiolation/cyclization at the anode followed by a reduction reaction at the cathode. A detailed mechanism for this cascade sequence has been established by carrying out several experimental investigations, including the recognition of key intermediates and DFT studies. An S-H insertion at the diazo center is also possible in slightly modified reaction conditions, making this electrochemical approach involving diazo compounds more versatile.

## ASSOCIATED CONTENT

### Supporting Information

The Supporting Information is available free of charge: Experimental details and spectroscopic data for all products, full Gaussian reference, Cartesian coordinates, electronic and free energies.

### Data Availability

Authors can confirm that all relevant data are included in the paper and/or its supplementary information files.

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### Author Contributions

JK, DS, YH and S conducted the experiments. M and AC performed theoretical calculations. YH solved X-ray structures. PC and JK wrote the manuscript and conceived this study. All authors have given approval to the final version of the manuscript.

## CONFLICTS OF INTEREST

There is no conflicts of interest to declare.

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## REFERENCES

1. Doyle, M. P., Duffy R., Ratnikov, M. & Zhou, L. Catalytic carbene insertion into C–H bonds. *Chem. Rev.* **110**, 704–724 (2010).
2. Gillingham, D. & Fei, N. Catalytic X–H insertion reactions based on carbenoids. *Chem. Soc. Rev.* **42**, 4918–4931 (2013).
3. Ciszewski, L. W., Jasińska, K. R. & Gryko, D. Recent developments in photochemical reactions of diazo compounds. *Org. Biomol. Chem.* **17**, 432–448 (2019).
4. 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.* **49**, 6833–6847 (2020).
5. Durka, J., Turkowska, J. & Gryko, D. Lightning Diazo Compounds? *ACS Sustainable Chem. Eng.* **9**, 8895–8918 (2021).
6. Empel, C., Pei, C. & Koenigs, R. M. Unlocking novel reaction pathways of diazoalkanes with visible light. *Chem. Commun.* **58**, 2788–2798 (2022).
7. He, Y., Huang, Z., Wu, K., Ma, J., Zhou, Y.-G. & Yu, Z. Recent advances in transition-metal-catalyzed carbene insertion

- to C–H bonds. *Chem. Soc. Rev.* **51**, 2759–2852 (2022).
- 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.* **59**, 7346–7360 (2023).
  - Zhang, Z. & Gevorgyan, V. Visible Light-Induced Reactions of Diazo Compounds and Their Precursors. *Chem. Rev.* **124**, 7214–7261 (2024).
  - Guo, X. & Hu, W. Novel multicomponent reactions via trapping of protic onium ylides with electrophiles. *Acc. Chem. Res.* **46**, 2427–2440, (2013).
  - Mao, H., Tang, Z., Hu, H., Cheng, Y., Zheng, W.-H. & Zhu, C. Lewis base mediated halogenation/semipinacol rearrangement of diazo compounds: new access to  $\alpha$ -halo-quaternary ketones. *Chem. Commun.* **50**, 9773–9775 (2014).
  - Hari, D. P. & Waser, J. Copper-catalyzed oxy-alkynylation of diazo compounds with hypervalent iodine reagents. *J. Am. Chem. Soc.* **138**, 7, 2190–2193 (2016).
  - Yuan, W., Eriksson, L. & Szabý, K. J. Rhodium-catalyzed geminal oxyfluorination and oxytrifluoromethylation of diazocarbonyl compounds. *Angew. Chem. Int. Ed.* **55**, 8410–8415 (2016).
  - Döben, N., Yan, H., Kischkewitz, M., Mao, J. & Studer, A. Intermolecular acetoxyaminoalkylation of  $\alpha$ -diazo amides with (diacetoxyiodo)benzene and amines. *Org. Lett.* **20**, 7933 (2018).
  - Yu, J., Chen, L. & Sun, J. Copper-catalyzed oxy-aminomethylation of diazo compounds with *N,O*-acetals. *Org. Lett.* **21**, 1664 (2019).
  - Ansari, M. A., Khan, S., Ray, S., Shukla, G. & Singh, M. S. [2 + 3] Annulative coupling of tetrahydroisoquinolines with arylodonio diazo compounds to access 1,2,4-triazolo[3,4-*a*]isoquinolines. *Org. Lett.* **24**, 6078–6082, (2022).
  - Lu, H., Dzik, W. I., Xu, X., Wojtas, L., de Bruin, B. & Zhang, X. P. Experimental evidence for cobalt(III)-carbene radicals: key intermediates in cobalt(II)-based metalloradical cyclopropanation. *J. Am. Chem. Soc.* **133**, 8518 (2011).
  - Zhang, J., Jiang, J., Xu, D., Luo, Q., Wang, H., Chen, J., Li, H., Wang, Y. & Wan, X. Interception of cobalt-based carbene radicals with  $\alpha$ -aminoalkyl radicals: A tandem reaction for the construction of  $\beta$ -ester- $\gamma$ -amino ketones. *Angew. Chem. Int. Ed.* **54**, 1231 (2015).
  - Wang, N.-N., Hao, W.-J., Zhang, T.-S., Li, G., Wu, Y.-N., Tu, S.-J. & Jiang, B. Metal-free C(sp<sup>3</sup>)–H functionalization: Oxidative carbo-oxygenation of  $\alpha$ -diazo carbonyls via radical dediazotization. *Chem. Commun.* **52**, 5144 (2016).
  - Wang, Y., Ma, L., Ma, M., Zheng, H., Shao, Y. & Wan, X. Bu<sub>4</sub>Ni-catalyzed cross-coupling between sulfonyl hydrazides and diazo compounds to construct  $\beta$ -carbonyl sulfones using molecular oxygen. *Org. Lett.* **18**, 5082 (2016).
  - Ma, M., Hao, W., Ma, L., Zheng, Y., Lian P. & Wan, X. Interception of radicals by molecular oxygen and diazo compounds: Direct synthesis of oxalate esters using visible-light catalysis. *Org. Lett.* **20**, 5799 (2018).
  - Li, P., Zhao, J., Shi, L., Wang, J., Shi, X. & Li, F. Iodine-catalyzed diazo activation to access radical reactivity. *Nat. Commun.* **9**, 1972 (2018).
  - Francke, R. & Little, R. D. Redox catalysis in organic electrosynthesis: basic principles and recent developments. *Chem. Soc. Rev.* **43**, 2492–2521 (2014).
  - Yan, M., Kawamata, Y. & Baran, P. S. Synthetic organic electrochemical methods since 2000: On the verge of a renaissance. *Chem. Rev.* **117**, 13230–13319 (2017).
  - Wiebe, A., Gieshoff, T., Möhle, S., Rodrigo, E., Zirbes, M. & Waldvogel, S. R. Electrifying organic synthesis. *Angew. Chem. Int. Ed.* **57**, 5594–5619 (2018).
  - Tang, S., Liu, Y. & Lei, A. Electrochemical oxidative cross-coupling with hydrogen evolution: A green and sustainable way for bond formation. *Chem.* **4**, 27–45 (2018).
  - Jiang, Y., Xu, K. & Zeng, C. Use of Electrochemistry in the synthesis of heterocyclic structures. *Chem. Rev.* **118**, 4485–4540 (2018).
  - Sauermann, N., Meyer, T. H., Qiu, Y. & Ackermann, L. Electrocatalytic C–H activation. *ACS Catal.* **8**, 7086–7103 (2018).
  - Möhle, S., Zirbes, M., Rodrigo, E., Gieshoff, T., Wiebe, A. & Waldvogel, S. R. Modern electrochemical aspects for the synthesis of value-added organic products. *Angew. Chem. Int. Ed.* **57**, 6018–6041 (2018).
  - Yoshida, J. I., Shimizu, A. & Hayashi, R. Electrogenerated cationic reactive intermediates: The pool method and further advances. *Chem. Rev.* **118**, 4702–4730 (2018).
  - Novaes, L. F. T., Liu, J., Shen, Y., Lu, L., Meinhardt, J. M. & Lin, S. Electrocatalysis as an enabling technology for organic

- synthesis. *Chem. Soc. Rev.* **50**, 7941–8002 (2021).
32. Saha, D., Taily, I. M., Kumar, R. & Banerjee, P. Electrochemical rearrangement protocols towards the construction of diverse molecular frameworks. *Chem. Commun.* **57**, 2464–2478 (2021).
  33. Leech, M. C. & Lam, K. A practical guide to electrosynthesis. *Nat. Rev. Chem.* **6**, 275–286 (2022).
  34. Rein, J., Zacate, S. B., Mao, K. & Lin, S. A tutorial on asymmetric electrocatalysis. *Chem. Soc. Rev.* **52**, 8106–8125 (2023).
  35. Xiong, M., Liang, X., Gao, Z., Lei, A. & Pan, Y. Synthesis of isoxazolines and oxazines by electrochemical intermolecular [2 + 1 + n] annulation: Diazo compounds act as radical acceptors. *Org. Lett.* **21**, 9300–9305 (2019).
  36. Yang, D., Guan, Z., Peng, Y., Zhu, S., Wang, P., Huang, Z., Alhumade, H., Gu, D., Yi, H. & Lei, A. Electrochemical oxidative difunctionalization of diazo compounds with two different nucleophiles. *Nat. Chem.* **14**, 1476 (2023).
  37. Zhan, L., Tao, Y.-C., Gao, L., He, M.-X., Pan, Y.-M., Zhang, Y., Ma, X.-L. & Mo, Z.-Y. Electrochemical oxidative difunctionalization of diazo compounds with diselenides and nucleophiles. *Org. Lett.* **26**, 4071–4076 (2024).
  38. He, Z., Zhao, W., Li, Y., Yu, Y. & Huang, F. Electrochemical S–H and O–H insertion reactions from thiols or salicylic acids with diazo esters. *Org. Biomol. Chem.* **20**, 8078–8082 (2022).
  39. Jiao, J., Yan, Y., Ke, Q., Zhang, Y., Huang, H., Gao, Q., Liu, J. & Wang, X. Paired electrolysis enables decarboxylative coupling of alkenyl acids with diazo compounds. *Org. Chem. Front.* **10**, 2968–2975 (2023).
  40. Jasińska, K. R., Szeptuch, Z., Kubeiszewski, H. & Kowaluk, A. Electrochemical cycloaddition reactions of alkene radical cations: A route toward cyclopropanes and cyclobutanes. *Org. Lett.* **25**, 1142–1146 (2023).
  41. Hussain, Y., Empel, C., Koenigs, R. M. & Chauhan, P. Carbene formation or reduction of the diazo functional group? An unexpected solvent-dependent reactivity of cyclic diazo imides. *Angew. Chem. Int. Ed.* **135**, e202309184 (2023).
  42. Dénès, F., Pichowicz, M., Povie, G. & Renaud, P. Thiyl radicals in organic synthesis. *Chem. Rev.* **114**, 2587–2693 (2014).
  43. Hortmann, A. G., Aron, A. J. & Bhattacharya, A. K. 3H-1,2-Benzodithiole oxides: Studies directed toward the generation of o-thiobenzoquinone methide and benzo[b]thiete. *J. Org. Chem.* **17**, 3374–3378 (1978).
  44. Mao, Y.-L. & Bdoekelheide, V. Benzocyclobutene-o-xylylene valence tautomerization: oxygen and sulfur analogs. *Proc. Natl. Acad. Sci. USA.* **77**, 1732–1735 (1980).
  45. Zu, L., Xie, H., Li, H., Wang, J., Jiang, W. & Wang, W. Chiral amine thiourea-promoted enantioselective domino michael-aldol reactions between 2-mercaptobenzaldehydes and maleimides. *Adv. Synth. Catal.* **349**, 1882–1886 (2007).
  46. See supporting information.
  47. Huang, B., Suna, Z. & Sun, G. Recent progress in cathodic reduction-enabled organic electrosynthesis: Trends, challenges, and opportunities. *eScience* **2**, 243–277 (2022).
  48. Huang, B., Li, Y., Yang, C. & Xia, W. Electrochemical 1,4-reduction of  $\alpha,\beta$ -unsaturated ketones with methanol and ammonium chloride as hydrogen sources. *Chem. Commun.* **55**, 6731–6734 (2019).
  49. Liu, X., Liu, R., Qiu, J., Cheng, X. & Li, G. Chemical-reductant-free electrochemical deuteration reaction using deuterium oxide. *Angew. Chem. Int. Ed.* **59**, 13962–13967 (2020).
  50. Kolb, S. & Werz, D. B. Site-selective hydrogenation/deuteration of benzylic olefins enabled by electroreduction using water. *Chem. Eur. J.* **29**, e202300849 (2023).
  51. Yang, K., Feng, T. & Qiu, Y. Organo-mediator enabled electrochemical deuteration of styrenes. *Angew. Chem. Int. Ed.* **62**, e202312803 (2023).
  52. Kolb, S. & Werz, D. B. Correspondence on “Organo-mediator enabled electrochemical deuteration of styrenes.” *Angew. Chem. Int. Ed.* **24**, e202316037 (2023).
  53. Activation strain analysis is done to further rationalize the energy difference between TSs  $[E-B]^\ddagger$  and  $[E'-B']^\ddagger$ . The destabilizing distortion of the thiyl radical (A) and diazo imide 1a is found to be more in the higher energy TS  $[E'-B']^\ddagger$ . Interestingly, the stabilizing interaction energy between the thiyl radical (A) and diazo imide 1a is found to be comparable in both TSs. The overall balance between distortion and interaction is in favour of the lower energy TS  $[E-B]^\ddagger$ .
  54. See section **S8**. in the Supporting Information for more details (all the DFT-related Figures and Tables).

