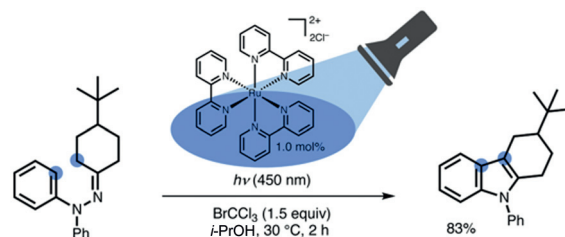# Photoredox Fischer Indole Synthesis

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**Abstract** Visible light photoredox conditions were applied to the traditional Fischer indole synthesis. N,N-Diarylhydrazones were efficiently converted into the corresponding indoles even at 30 °C by treatment with bromotrichloromethane in the presence of Ru(bpy)$_3$Cl$_2$·6H$_2$O as the photocatalyst. Electrochemical study revealed the viability of oxidative quenching cycle for the photocatalysis, which set the basis for proposing the redox-based reaction mechanism.

Fischer indole synthesis is a well-known reaction that has a long history and broad range of applications in organic synthesis.[1] This traditional transformation is still often in use because of its ready availability of the starting materials and economical one-step experimental procedure. Various acids and activating methods have already been developed for this reaction (Scheme 1a). Typically, the reaction proceeds from hydrazone **1** via the formation of alkenylhydrazine **2** that then goes through [3,3]-sigmatropic rearrangement, cyclization to form indoline **4**, and elimination of ammonia that lead to the core of indole **5**. In addition to the use of typical Brønsted acids as reagents/catalysts that are occasionally associated with side reactions, thermal reaction conditions are sometimes employed to give better results even though high temperature is required for efficient transformation (180–250 °C).[2] These potential drawbacks prompted chemists to develop alternative reaction conditions for the Fischer indole synthesis.[3] One of the most interesting activating reagents that has been developed is trifluoroacetic anhydride[4] with which trifluoroacetylation of sp$^2$ nitrogen atom of hydrazone **6**, instead of protonation, mediates the activation of hydrazone moiety to form the
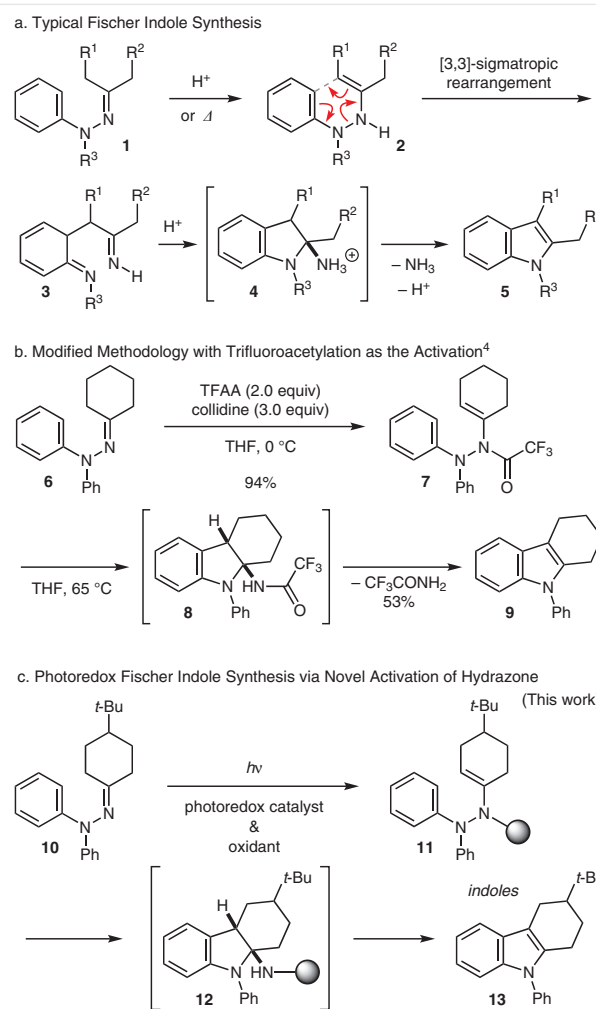


**Scheme 1** Fischer indole synthesis and its mode of activation on hydrazone moiety

isolable trifluoroacetylated hydrazine **7** (Scheme 1b). Final removal of trifluoroacetamide from indoline intermediate **8** gives indole target **9**. During our research campaign toward various application of photoredox reaction conditions,[5] we envisioned to implement this concept to Fischer indole synthesis as an attempt to develop milder reaction conditions. Herein, we describe novel photoredox conditions for Fischer indole synthesis of certain diphenylhydrazones (Scheme 1c). This manuscript deals with the brief scope of the developed reaction, as well as the mechanistic reasoning of this novel transformation as a foundation to further researches.

For the optimization of the reaction conditions, 4-*tert*-butylcyclohexanone diphenylhydrazone **10** was selected as

the standard substrate as the precursor to indole **13**. Table 1 shows the details of our optimization of the conditions. The scope of oxidants was examined first. Hydrazone **10** was reacted with arrays of oxidants (1.5 equiv) under the irradiating conditions (450 nm) in the presence of Ru(bpy)$_3$Cl$_2$·6H$_2$O (**14**, 1.0 mol%) in DMF. Bromotrichloromethane (BrCCl$_3$) showed better reactivity than diethyl bromomalonate or carbon tetrachloride (Table 1, entries 1–3). With bromotrichloromethane as the best performing oxidant, the solvent effect was examined next. As can be seen from entries 4–6, lower conversion of **10** was observed in DMSO, THF, and CH$_2$Cl$_2$. By contrast, the treatment of **10** in methanol improved the reaction efficiency, providing in-

**Table 1** Optimization of the Reaction Conditions[a]
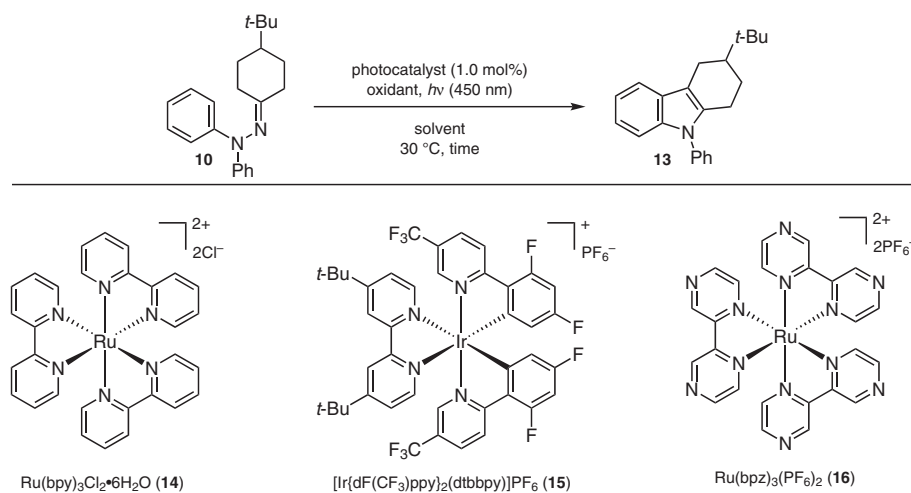


| Entry | Oxidant | Photocatalyst | Solvent | Conv. (%)[b] | Yield (%)[b] |
|---|---|---|---|---|---|
| 1 | BrCCl$_3$ | **14** | DMF | >99 | 48 |
| 2 | BrCH(CO$_2$Et)$_2$ | **14** | DMF | 83 | 28 |
| 3 | CCl$_4$ | **14** | DMF | 60 | 40 |
| 4 | BrCCl$_3$ | **14** | DMSO | 95 | 45 |
| 5 | BrCCl$_3$ | **14** | THF | 31 | 22 |
| 6 | BrCCl$_3$ | **14** | CH$_2$Cl$_2$ | 39 | 17 |
| 7 | BrCCl$_3$ | **14** | MeOH | 90 | 64 |
| 8 | BrCCl$_3$ | **14** | EtOH | >99 | 73 |
| 9 | BrCCl$_3$ | **14** | *t*-BuOH | 17 | 7 |
| 10 | BrCCl$_3$ | **14** | *i*-PrOH | >99 | 85 (83)[c] |
| 11 | BrCCl$_3$ | **15** | *i*-PrOH | >99 | 85 |
| 12 | BrCCl$_3$ | **16** | *i*-PrOH | 14 | 6 |
| 13 | BrCCl$_3$ | none | *i*-PrOH | 1 | 1 |
| 14[d] | BrCCl$_3$ | none | *i*-PrOH | >99 | 90 |

[a] The reactions were carried out using hydrazone **10** (0.1 mmol) and oxidant (1.5 equiv) in the presence of photocatalyst (1.0 mol%) in solvent (0.05 M) at 30 °C with irradiation of blue LED (450 nm) under an argon atmosphere for 2 h.
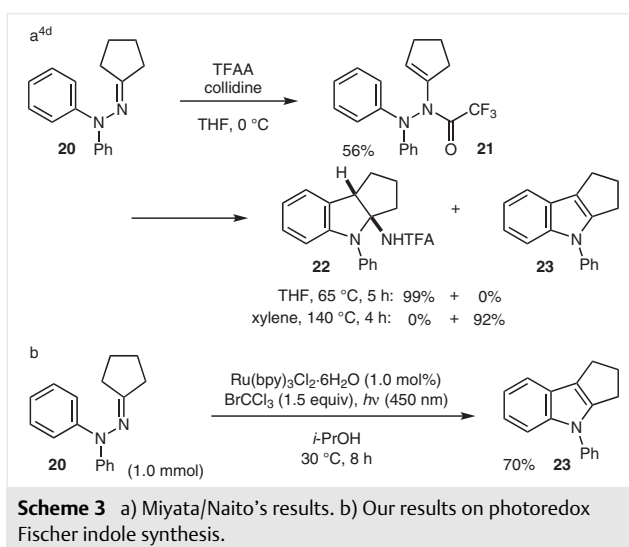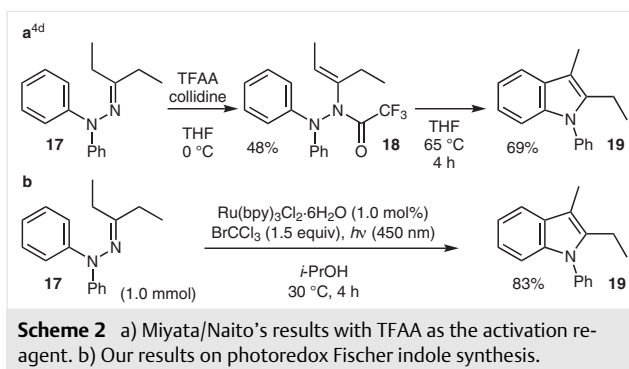[b] $^1$H NMR yields.
[c] Isolated yield.
[d] Reaction time was 8 h.

dole **13** in 64% yield (entry 7). Screening of other alcoholic solvents (entry 8–10) revealed that 2-propanol was the optimal solvent among examined (83% isolated yield, entry 10). Change of the photocatalyst to [Ir{dF(CF$_3$)ppy}$_2$(dtbb-py)]PF$_6$ (**15**) (entry 11), showed comparable reactivity, while Ru(bpz)$_3$(PF$_6$)$_2$ (**16**) mediated more sluggish reaction (entry 12). Interestingly, the conditions without any photocatalyst gave the same result under the prolonged reaction conditions (entries 13, 14). From the optimization above, the conditions of entry 10 [hydrazone (0.05 M), BrCCl$_3$ (1.5 equiv), **14** (1.0 mol%), irradiation (450 nm), 2-propanol] was determined to be the best conditions.

To briefly illustrate the scope of the reaction, several substrates were subjected to the present reaction conditions. Scheme 2 shows the results with 3-pentanone diphenylhydrazone **17**. As previously reported, activation by TFAA gives the trifluoroacetate **18**. Subsequent heating in THF at 65 °C mediates [3,3]-sigmatropic rearrangement and formation of indoline moiety, followed by the ready elimination of trifluoroacetamide to give indole **19** (Scheme 2a).[4d] Our optimized reaction conditions to **17** gave the same indole **19** in good yield in one step even at 30 °C (Scheme 2b). Cyclopentanone diphenylhydrazone **20** is reported to give trifluoroacetyl adduct **21** when treated with TFAA and collidine (Scheme 3a).[4d] Interestingly, heating **21** in THF at 65 °C gives the cyclized indoline product **22**. This indicated the ready [3,3]-sigmatropic rearrangement and the cyclization to form indoline moiety, while the elimination of trifluoroacetamide does not proceed readily. This fact could be ascribed to the formation of strained iminium cation intermediate and product that retarded the elimination. Under the refluxing conditions of xylene at 140 °C, this elimination proceeds to afford the indole product **23** in good yield. Our new photoredox conditions for the same substrate **20** gave the indole product **23** in 70% yield even at 30 °C, with the prolonged reaction time (Scheme 3b). The formation of indole **23** was not associated with the formation of any remaining intermediate, indicating the increased tendency toward the removal of the nitrogen functionality from the indoline intermediate. Our preliminary study indicated almost ignorable reactivity for the synthesis of NH, *N*-Me, *N*-Bn, and *N*-Boc indoles.



**Scheme 2** a) Miyata/Naito's results with TFAA as the activation reagent. b) Our results on photoredox Fischer indole synthesis.



**Scheme 3** a) Miyata/Naito's results. b) Our results on photoredox Fischer indole synthesis.

The mechanism of this photoredox Fischer indole synthesis has two possibilities (Scheme 4). Cycle A involves the oxidative quenching cycle where photoactivated ruthenium species [Ru(bpy)$_3$]$^{2+*}$ is oxidized by the oxidant (BrCCl$_3$ is reduced first), and the other, cycle B, involves the reductive quenching where the photoactivated species is reduced by the hydrazone (hydrazone is oxidized first). Photophysical and electrochemical experiments were thus conducted to see the electrochemical reactivity of the reactants and to



**Scheme 4** Two possible catalytic cycles for the photoredox Fischer indole synthesis
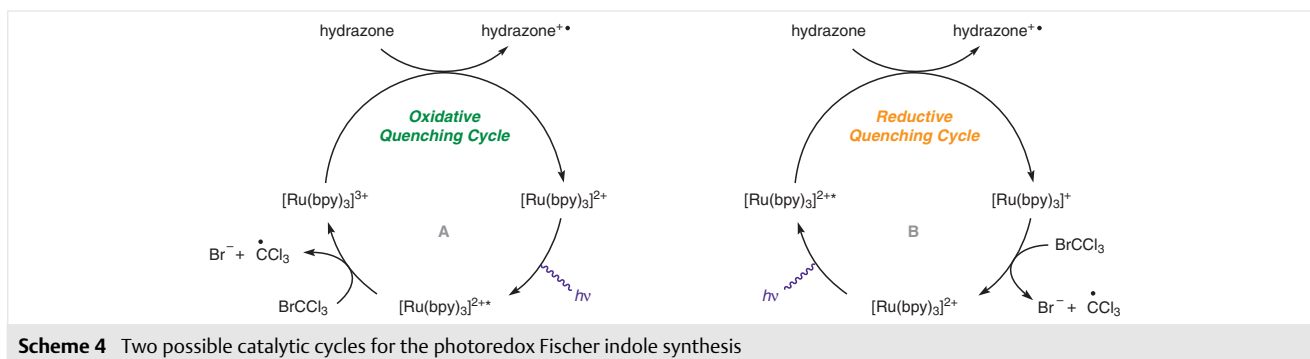
determine the reaction mechanism in the current photoredox Fischer indole synthesis.

First, luminescent quenching experiment was conducted to determine the plausible mechanistic cycles A and B. As shown in the data in Supporting Information, similar luminescent quenching of photoactivated $Ru(bpy)_3Cl_2$ was observed with low solution concentration. This result indicated the possibility of electron transfer between the photocatalyst and both of the substrates. However, it is still difficult to exclude the possibility of back-electron transfer. To clarify the working mechanism of the reaction, electrochemical experiments were next examined. Figure 1 shows the cyclic voltammogram of hydrazone **10** (blue) referenced to redox couple of decamethylferrocene ($Fc^*/Fc^{*+}$) (black). In this manuscript, reported electrochemical potentials of known compounds versus SCE was converted to the values referenced to $Fc^*/Fc^{*+}$ (in 2-propanol) according to the Lay's report.[6] Thus the redox potential of $Fc^*/Fc^{*+}$ (55 mV in 2-propanol vs Ag/AgCl) was estimated to be 10 mV (vs SCE) through the known potential of Ag/AgCl (–45 mV vs SCE). Cyclic voltammogram of hydrazone **10** in Figure 1 indicates almost ignorable amount of current at the excited state reduction potential of $[Ru(bpy)_3]^{2+*}$ ($E_{1/2}^{*II/I}$ = +0.76 V [vs $Fc^*/Fc^{*+}$])[7] (orange). This indicates the inability of $[Ru(bpy)_3]^{2+*}$ to oxidize hydrazone **10** within the reductive quenching cycle. Reductive quenching cycle (cycle B) is thus proposed unlikely for the current photoredox Fischer indole synthesis. This is because our Fischer indole synthesis requires $BrCCl_3$ as oxidant. Photo-excitation of $Ru(bpy)_3$ initiates the catalytic reaction cycle. If $Ru(bpy)_3$ initiates the reductive quenching cycle, some intermediates from hydrazone should be observed. However, we did not observe the product effectively. These results suggest that oxidative quenching cycle with oxidant is plausible in terms of the mechanistic investigation. The reaction could be thus considered to involve the oxidative quenching cycle (cycle A) that mediates the well-known reduction of $BrCCl_3$ ($E_{1/2,red}$ = –0.19 V [vs $Fc^*/Fc^{*+}$])[8] at the oxidation potential of the photocatalyst. This was further confirmed by the cyclic voltammograms in the presence of $BrCCl_3$ (blue line) in Figure 2, that indicate the cathodic current at the excited state oxidation potential of $[Ru(bpy)_3]^{2+*}$ ($E_{1/2}^{III/*II}$ = –0.82 V [vs $Fc^*/Fc^{*+}$])[7] at the green line. The reported reduction potentials ($E_{1/2,red}$) of $CCl_4$ and $BrCH(CO_2Et)_2$ are –1.94 V [vs $Fc^*/Fc^{*+}$] and –0.63 V [vs $Fc^*/Fc^{*+}$], respectively.[9] These values support that the single-electron reduction of $BrCCl_3$ ($E_{1/2,red}$ = –0.19 V [vs $Fc^*/Fc^{*+}$]) by the excited state $[Ru(bpy)_3]^{2+*}$ ($E_{1/2}^{III/*II}$ = –0.82 V [vs $Fc^*/Fc^{*+}$]) is kinetically preferred than those of $CCl_4$ and $BrCH(CO_2Et)_2$. These discussions are consistent with the results of entries 10–12 in Table 1. With $[Ir\{dF(CF_3)ppy\}_2(dtbbpy)]PF_6$ ($E_{1/2}^{IV/*III}$ = –0.90 V [vs $Fc^*/Fc^{*+}$])[10] as the photocatalyst, almost the same redox characteristics indicate the same oxidative quenching mechanism.[11] The ground state reduction potential of $Ir^{4+}$ intermediate ($E_{1/2}^{IV/III}$ = +1.68 V [vs $Fc^*/Fc^{*+}$])[10] is similar to

that of $Ru^{3+}$ ($E_{1/2}^{III/II}$ = +1.28 V [vs $Fc^*/Fc^{*+}$]),[7] which also supports the subsequent oxidation step (Table 1, entry 11). In turn, the excited species $[Ru(bpz)_3]^{2+*}$ ($E_{1/2}^{III/*II}$ = –0.27 V [vs $Fc^*/Fc^{*+}$])[12] has weaker oxidation potential for the reduction of $BrCCl_3$. This is consistent with the slower reaction (entry 12).
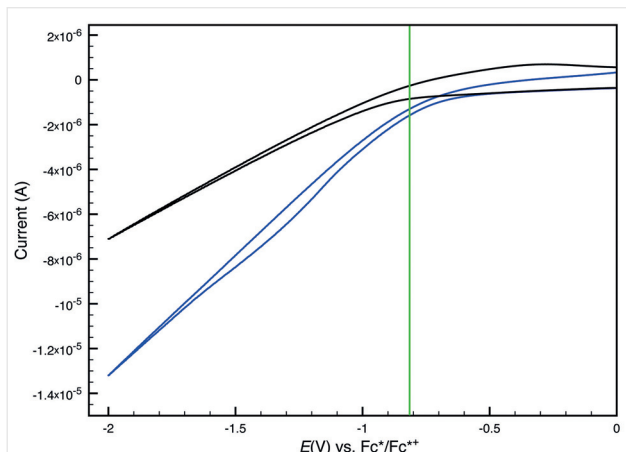


**Figure 1** Cyclic voltammograms (100 mV/s scan rate) of blank (black) and hydrazone **10** (5.0 mM, blue) recorded in 0.1 M tetrabutylammonium hexafluorophosphate 2-propanol electrolyte. Electrochemical potential was referenced to $Fc^*/Fc^{*+}$.
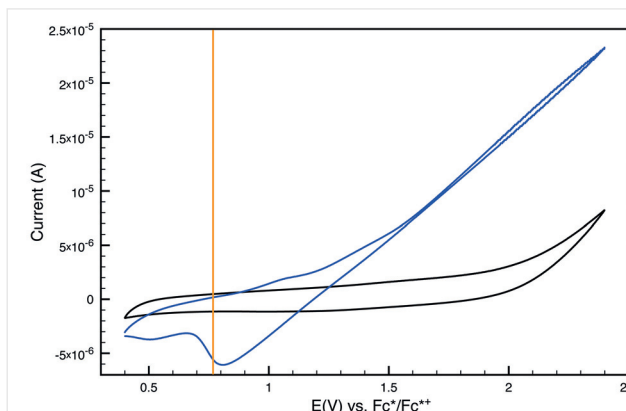


**Figure 2** Cyclic voltammograms (100 mV/s scan rate) of blank (black) and $BrCCl_3$ (5.0 mM, blue) recorded in 0.1 M tetrabutylammonium hexafluorophosphate 2-propanol electrolyte. Electrochemical potential was referenced to $Fc^*/Fc^{*+}$.

Collectively, the reaction mechanism is in accordance with the following proposal (Scheme 5). First, $[Ru(bpy)_3]^{2+}$ (**14**) is photoactivated to $[Ru(bpy)_3]^{2+*}$ that reduces $BrCCl_3$ to generate $[Ru(bpy)_3]^{3+}$, bromide anion, and trichloromethyl radical. The radical species attacks the nitrogen atom of C=N bond of hydrazone **10** leading to α-aminoalkyl radical **24**, which would be oxidized to cation **25** by single-electron oxidation mediated by $[Ru(bpy)_3]^{3+}$.[13] This regioselectivity may be associated with the fact that electron-deficient radicals such as acyl radicals are known to favor the attack at

**Scheme 5** Proposed reaction mechanism for the photoredox Fischer indole synthesis
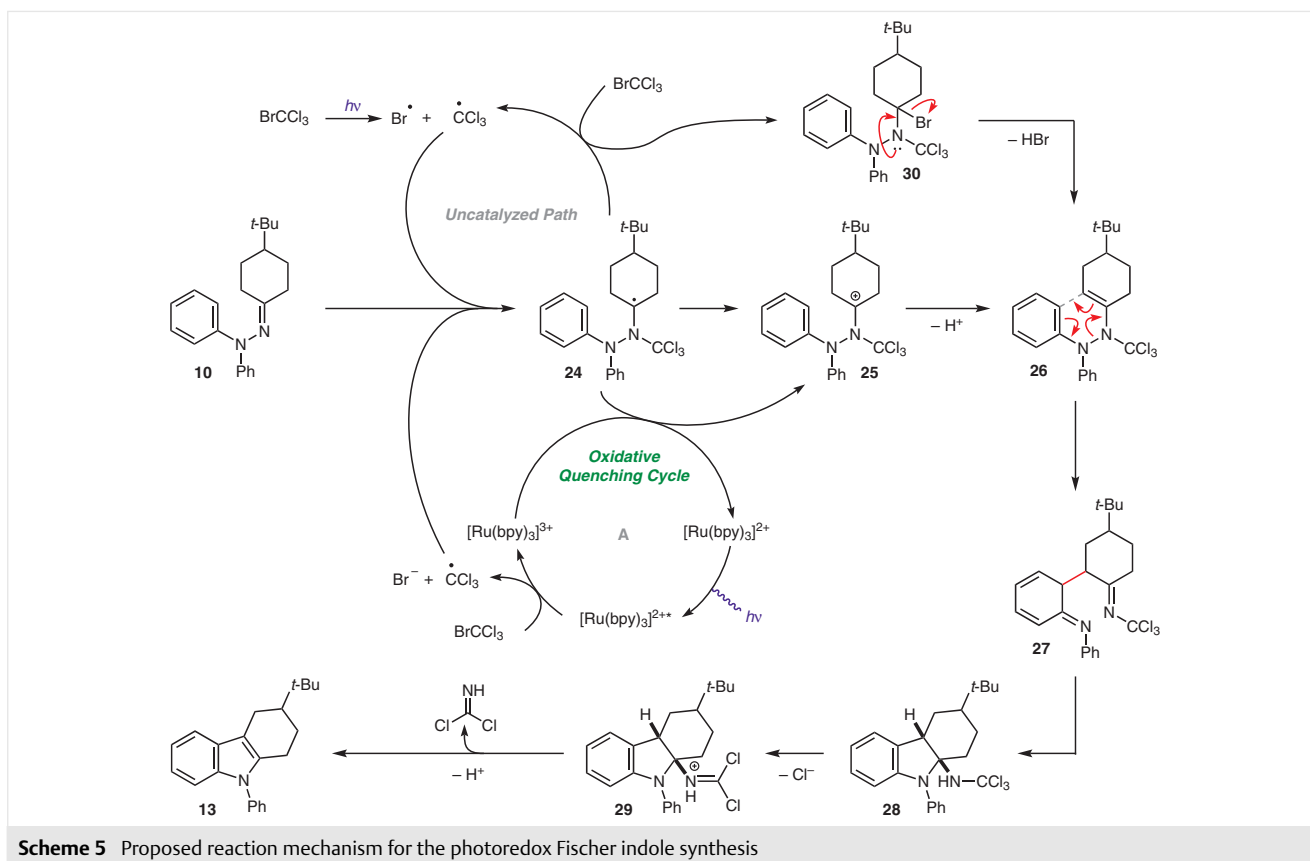
nitrogen atom of imines.[14] Deprotonation affords alkenyl-hydrazine **26** that is then susceptible to [3,3]-sigmatropic rearrangement to form a C–C bond to give **27**. The following cyclization forms indoline **28**. The ease of elimination of nitrogen functionality under the current reaction conditions indicate the increased leaving ability, possibly exerted by the formation of iminium ion **29**, formed by expelling the chloride. Final removal of iminophosgene and isomerization gives indole **13**. Slow formation of indole **13** without the addition of photocatalyst could be similarly reasoned by considering the uncatalyzed photoactivation of BrCCl$_3$ to give bromine radical and trichloromethyl radical,[15] which would mediate a radical chain reaction to generate the active species **24**. This mechanism could account for the typical induction period of the reaction before following the similar transformations to give the same alkenylhydrazine **26** possibly through **30**.

In conclusion, novel photoredox Fischer indole synthesis was developed employing the combination of photocatalyst and BrCCl$_3$. From the results on the selected substrates, the methodology thus developed suggests its usability for constructing *N*-aryl 2,3-disubstituted indoles. Mechanistic studies revealed that the oxidative quenching cycle is the

plausible catalytic mechanism. Trichloromethyl radical is suggested to attack the nitrogen atom of hydrazone moiety and helps the formation of alkenylhydrazine as the efficient substrate of [3,3]-sigmatropic rearrangement, followed by the ready removal of nitrogen functionality for the facile formation of indole core even at 30 °C.

All nonaqueous reactions were carried out under an inert atmosphere of N$_2$ in oven-dried glassware, unless otherwise noted. DMF, DMSO, MeCN, and 2-propanol were distilled over CaH$_2$. All other reagents were commercially available and used without further purification, unless otherwise noted. Analytical TLC was performed on Merck precoated analytical plates, 0.25 mm thick, silica gel 60 F$_{254}$. Preparative flash chromatography was performed using Silica Gel (AP-300, irregular, 38–75 μm) purchased from Toyotakako Co., Ltd. $^1$H and $^{13}$C NMR spectra were recorded on a JEOL JNM-ECA600 or JNM-ECZ600 spectrometer. All $^1$H NMR spectra are reported in units, parts per million (ppm) downfield from TMS as the internal standard (0.00 ppm) or CHCl$_3$ (7.26 ppm) and coupling constants are indicated in hertz (Hz). Standard abbreviations are used for spin multiplicity. All $^{13}$C NMR spectra are reported in ppm relative to the central line of the triplet for CDCl$_3$ (77.0 ppm). High resolution mass spectra (HRMS) were obtained on a Bruker micrOTOF II spectrometer. Melting points, determined on a Stanford Research Systems MPA100 melting point apparatus, are uncorrected.

## 2-[4-(*tert*-Butyl)cyclohexylidene]-1,1-diphenylhydrazine (10); Typical Procedure for the Synthesis of *N,N*-Diphenylhydrazones

A 300 mL round-bottomed flask equipped with a magnetic stir bar was charged under argon gas with 1,1-diphenylhydrazine (6.8 g, 37 mmol), 4-*tert*-butylcyclohexanone (5.4 g, 35 mmol), AcOH (20 μL, 0.35 mmol), and EtOH (70 mL). The resulting mixture was stirred at 60 °C for 15 h and cooled to r.t. The mixture was partitioned between $Et_2O$ and $H_2O$. The organic phase was collected and the aqueous phase was extracted with $Et_2O$ (2 ×). The combined organic extracts were washed with brine and dried (anhyd $Na_2SO_4$), filtered; and concentrated in vacuo. The residue was purified by column chromatography on silica gel (*n*-hexane/EtOAc 100:1 to 40:1) to afford hydrazone **10** (7.8 g, 24 mmol, 70%) as a pale brown solid, mp 58.0–59.0 °C; $R_f$ = 0.59 [*n*-hexane/EtOAc 5:1, UV, PMA (phosphomolybdic acid)].

$^1$H NMR (CDCl$_3$, 600 MHz): δ = 7.27 (t, $J$ = 7.6 Hz, 4 H), 7.04 (d, $J$ = 8.3 Hz, 4 H), 7.00 (dd, $J$ = 8.3, 7.6 Hz, 2 H), 3.10 (m, 1 H), 2.79 (m, 1 H), 2.25 (ddd, $J$ = 14.5, 13.1, 4.8 Hz, 1 H), 2.03 (m, 1 H), 1.76 (m, 1 H), 1.53 (ddd, $J$ = 14.5, 13.8, 5.5 Hz, 1 H), 1.33 (ddd, $J$ = 13.1, 12.4, 4.1 Hz, 1 H), 1.23 (m, 1 H), 0.99 (ddd, $J$ = 13.8, 13.1, 4.1 Hz, 1 H), 0.85 (s, 9 H).

$^{13}$C NMR (CDCl$_3$, 150 MHz): δ = 175.4, 148.6, 128.9, 122.5, 120.9, 47.2, 35.1, 32.4, 30.1, 27.8, 27.5, 26.5.

HRMS (APCI-MS, positive): $m/z$ [M + H]$^+$ calcd for $C_{22}H_{29}N_2$: 321.2325; found: 321.2335.

## 2-(Pentan-3-ylidene)-1,1-diphenylhydrazine (17)

Reaction of 3-pentanone (1.4 g, 16 mmol), 1,1-diphenylhydrazine (2.2 g, 12 mmol), AcOH (50 μL, 0.88 mmol), and EtOH (10 mL) at 90 °C for 12 h gave hydrazone **17** (2.0 g, 7.9 mmol, 66%) as a pale yellow oil after purification by column chromatography on silica gel (*n*-hexane/EtOAc 20:1 to 10:1); $R_f$ = 0.58 (*n*-hexane/EtOAc 5:1, UV, PMA).

$^1$H NMR (CDCl$_3$, 600 MHz): δ = 7.30 (dd, $J$ = 8.6, 7.4 Hz, 4 H), 7.08 (dd, $J$ = 8.6, 1.0 Hz, 4 H), 7.04 (t, $J$ = 7.4 Hz, 2 H), 2.49 (dd, $J$ = 15.1, 7.6 Hz, 2 H), 2.31 (dd, $J$ = 15.3, 7.7 Hz, 2 H), 1.26 (t, $J$ = 7.6 Hz, 3 H), 0.90 (t, $J$ = 7.7 Hz, 3 H).

$^{13}$C NMR (CDCl$_3$, 150 MHz): δ = 179.0, 148.6, 128.9, 122.5, 120.8, 29.0, 25.0, 11.2, 9.8.

HRMS (APCI-MS, positive): $m/z$ [M + H]$^+$ calcd for $C_{17}H_{21}N_2$: 253.1699; found: 253.1707.

## 2-Cyclopentylidene-1,1-diphenylhydrazine (20)

Reaction of cyclopentanone (1.26 g, 15 mmol), 1,1-diphenylhydrazine (2.2 g, 12 mmol), AcOH (50 μL, 0.88 mmol), and EtOH (10 mL) at 90 °C for 5 h gave hydrazone **20** (1.99 g, 7.95 mmol, 66%) as a pale yellow solid after purification by column chromatography on silica gel (*n*-hexane/EtOAc 20:1 to 10:1); mp 48.1–49.4 °C; $R_f$ = 0.45 (*n*-hexane/EtOAc 5:1, UV, PMA).

$^1$H NMR (CDCl$_3$, 600 MHz): δ = 7.29 (ddd, $J$ = 8.58, 7.38, 2.06 Hz, 4 H), 7.07 (dd, $J$ = 8.58, 1.20 Hz, 4 H), 7.04 (t, $J$ = 7.38 Hz, 2 H), 2.58 (t, $J$ = 7.38 Hz, 2 H), 2.03 (t, $J$ = 7.35 Hz, 2 H), 1.78–1.67 (m, 4 H).

$^{13}$C NMR (CDCl$_3$, 150 MHz): δ = 178.8, 148.2, 129.0, 122.8, 121.4, 33.8, 31.6, 24.9, 24.4.

HRMS (APCI-MS, positive): $m/z$ [M + H]$^+$ calcd for $C_{17}H_{19}N_2$: 251.1543; found: 251.1541.

## 3-(*tert*-Butyl)-9-phenyl-2,3,4,9-tetrahydro-1*H*-carbazole (13); Typical Procedure for the Photoredox Fischer Indole Synthesis

A 20 mL oven-dried J. Young Schlenk tube equipped with a magnetic stir bar was charged under argon with hydrazone **10** (32.0 mg, 0.10 mmol), Ru(bpy)$_3$Cl$_2$·6H$_2$O (0.75 mg, 0.0010 mmol), and 2-propanol

(2.0 mL), which was degassed three times by freeze–thaw process. BrCCl$_3$ (15 μL, 0.15 mmol) was added via syringe and the resulting mixture was irradiated by blue LED. After stirring at 30 °C for 2 h, the reaction mixture was quenched with sat. aq NaHCO$_3$ (1 mL). The mixture was partitioned between $Et_2O$ and $H_2O$. The organic phase was collected and the aqueous phase was extracted with $Et_2O$ (2 ×). The combined organic extracts were washed with brine and dried over anhyd $Na_2SO_4$ (ca. 1.0 g), filtered, and concentrated in vacuo. The residue was purified by column chromatography on silica gel (*n*-hexane/EtOAc 1:0 to 200:1) to afford indole **13** (25.1 mg, 0.083 mmol, 83%) as a clear oil; $R_f$ = 0.72 (*n*-hexane/EtOAc 5:1, UV, PMA).

$^1$H NMR (CDCl$_3$, 600 MHz): δ = 7.54–7.48 (m, 3 H), 7.40–7.35 (m, 3 H), 7.23 (dd, $J$ = 6.2, 2.1 Hz, 2 H), 7.11 (ddd, $J$ = 13.8, 6.9, 2.1 Hz, 2 H), 2.92 (dd, $J$ = 15.2, 4.8 Hz, 1 H), 2.69 (m, 1 H), 2.61 (dd, $J$ = 16.5, 5.5 Hz, 1 H), 2.50 (m, 1 H), 2.09 (m, 1 H), 1.60 (ddd, $J$ = 12.4, 4.8, 2.1 Hz, 1 H), 1.47 (ddd, $J$ = 24.8, 11.7, 4.8 Hz, 1 H), 1.01 (s, 9 H).

$^{13}$C NMR (CDCl$_3$, 150 MHz): δ = 138.1, 137.4, 135.9, 129.3, 127.8, 127.0, 126.9, 121.2, 119.6, 117.6, 111.4, 109.8, 45.3, 32.6, 27.5, 24.9, 24.1, 22.4.

HRMS (APCI-MS, positive): $m/z$ [M + H]$^+$ calcd for $C_{22}H_{26}N$: 304.2060; found: 304.2070.

## 2-Ethyl-3-methyl-1-phenyl-1*H*-indole (19)

Reaction of hydrazone **17** (252 mg, 1.0 mmol), Ru(bpy)$_3$Cl$_2$·6H$_2$O (7.5 mg, 0.010 mmol), BrCCl$_3$ (150 μL, 1.5 mmol), and 2-propanol (20 mL) at 30 °C with irradiation of blue LED for 4 h gave indole **19** (196 mg, 0.833 mmol, 83%) as a clear oil after purification by column chromatography on silica gel (*n*-hexane/EtOAc 1:0 to 100:1); $R_f$ = 0.68 (*n*-hexane/EtOAc 5:1, UV, PMA).

$^1$H and $^{13}$C NMR spectra were identical with the literature data.[16]

$^1$H NMR (CDCl$_3$, 600 MHz): δ = 7.55 (d, $J$ = 7.6 Hz, 1 H), 7.52 (t, $J$ = 7.6 Hz, 2 H), 7.44 (t, $J$ = 7.6 Hz, 1 H), 7.34 (d, $J$ = 6.9 Hz, 2 H), 7.12 (ddd, $J$ = 7.6, 6.9, 1.4 Hz, 1 H), 7.08 (ddd, $J$ = 7.6, 6.9, 1.4 Hz, 1 H), 7.03 (d, $J$ = 8.3 Hz, 1 H), 2.69 (dd, $J$ = 15.2, 7.6 Hz, 2 H), 2.34 (s, 3 H), 0.99 (t, $J$ = 7.6 Hz, 3 H).

$^{13}$C NMR (CDCl$_3$, 150 MHz): δ = 138.9, 138.4, 137.5, 129.3, 128.7, 128.3, 127.6, 121.1, 119.4, 117.9, 109.8, 107.2, 18.0, 14.3, 8.7.

## 4-Phenyl-1,2,3,4-tetrahydrocyclopenta[*b*]indole (23)

Reaction of hydrazone **20** (250 mg, 1.0 mmol), Ru(bpy)$_3$Cl$_2$·6H$_2$O (7.5 mg, 0.010 mmol), BrCCl$_3$ (150 μL, 1.5 mmol), and 2-propanol (20 mL) at 30 °C with irradiation of blue LED for 8 h gave indole **23** (164 mg, 0.704 mmol, 70%) as a clear oil after purification by column chromatography on silica gel (*n*-hexane/EtOAc 1:0 to 100:1); $R_f$ = 0.64 (*n*-hexane/EtOAc 5:1, UV, PMA).

$^1$H and $^{13}$C NMR spectra were identical with the literature data.[17]

$^1$H NMR (CDCl$_3$, 600 MHz): δ = 7.49 (m, 3 H), 7.44 (m, 3 H), 7.33 (m, 1 H), 7.11 (m, 2 H), 2.90 (dd, $J$ = 14.5, 7.6 Hz, 4 H), 2.55 (quint, $J$ = 6.9 Hz, 2 H).

$^{13}$C NMR (CDCl$_3$, 150 MHz): δ = 145.6, 140.9, 138.9, 129.4, 126.1, 125.0, 124.7, 120.9, 120.3, 120.1, 118.6, 110.7, 28.3, 26.2, 24.6.

## Supporting Information

Supporting information for this article is available online at https://doi.org/10.1055/s-0037-1611535.

## References

(1) (a) Robinson, B. *Chem. Rev.* **1963**, *63*, 373. (b) Robinson, B. *Chem. Rev.* **1969**, *69*, 227. (c) Robinson, B. *The Fischer Indole Synthesis*; John Wiley & Sons: New York, **1982**. (d) Hughes, D. L. *Org. Prep. Proced. Int.* **1993**, *25*, 607.

(2) Fitzpatrick, J. T.; Hiser, R. D. *J. Org. Chem.* **1957**, *22*, 1703.

(3) (a) Fischer, E. *Justus Liebigs Ann. Chem.* **1886**, *236*, 198. (b) Kissman, H. M.; Farnsworth, D. W.; Witkop, B. *J. Am. Chem. Soc.* **1952**, *74*, 3948. (c) Schiess, P.; Sendi, E. *Helv. Chim. Acta* **1978**, *61*, 1364. (d) Baccolini, G.; Todesco, P. E. *J. Chem. Soc., Chem. Commun.* **1981**, 563. (e) Maruoka, K.; Oishi, M.; Yamamoto, H. *J. Org. Chem.* **1993**, *58*, 7638. (f) Rebeiro, G. L.; Khadilkar, B. M. *Synthesis* **2001**, 370. (g) Mhaske, S. B.; Argade, N. P. *Tetrahedron* **2004**, *60*, 3417. (h) Dhakshinamoorthy, A.; Pitchumani, K. *Appl. Catal., A* **2005**, *292*, 305. (i) Lipińska, T. M.; Czarnocki, S. J. *Org. Lett.* **2006**, *8*, 367.

(4) (a) Miyata, O.; Kimura, Y.; Muroya, K.; Hiramatsu, H.; Naito, T. *Tetrahedron Lett.* **1999**, *40*, 3601. (b) Miyata, O.; Kimura, Y.; Naito, T. *Chem. Commun.* **1999**, 2429. (c) Miyata, O.; Kimura, Y.; Naito, T. *Synthesis* **2001**, 1635. (d) Miyata, O.; Takeda, N.; Kimura, Y.; Takemoto, Y.; Tohnai, N.; Miyata, M.; Naito, T. *Tetrahedron* **2006**, *62*, 3629. (e) Miyata, O.; Takeda, N.; Naito, T. *J. Synth. Org. Chem. Jpn.* **2006**, *64*, 1282.

(5) (a) Narayanam, J. M. R.; Stephenson, C. R. J. *Chem. Soc. Rev.* **2011**, *40*, 102. (b) Prier, C. K.; Rankic, D. A.; MacMillan, D. W. C. *Chem. Rev.* **2013**, *113*, 5322. (c) Shaw, M. H.; Twilton, J.; MacMillan, D. W. C. *J. Org. Chem.* **2016**, *81*, 6898. (d) Kärkäs, M. D.; Porco, J. A. Jr.; Stephenson, C. R. J. *Chem. Rev.* **2016**, *116*, 9683. (e) Romero, N. A.; Nicewicz, D. A. *Chem. Rev.* **2016**, *116*, 10075.

(6) (a) Noviandri, I.; Brown, K. N.; Fleming, D. S.; Gulyas, P. T.; Lay, P. A.; Masters, A. F.; Phillips, L. *J. Phys. Chem. B* **1999**, *103*, 6713. (b) Bard, A. J.; Faulkner, L. R. *Electrochemical Methods: Fundamentals and Applications*; John Wiley & Sons: New York, **2001**.

(7) Kalyanasundaram, K. *Coord. Chem. Rev.* **1982**, *46*, 159.

(8) Murayama, E.; Kohda, A.; Sato, T. *J. Chem. Soc., Perkin Trans. 1* **1980**, 947.

(9) Roth, H. G.; Romero, N. A.; Nicewicz, D. A. *Synlett* **2016**, *27*, 714.

(10) Lowry, M. S.; Goldsmith, J. I.; Slinker, J. D.; Rohl, R.; Pascal, R. A.; Malliaras, G. G.; Bernhard, S. *Chem. Mater.* **2005**, *17*, 5712.

(11) Nguyen, J. D.; D'Amato, E. M.; Narayanam, J. M. R.; Stephenson, C. R. J. *Nat. Chem.* **2012**, *4*, 854.

(12) Haga, M.; Dodsworth, E. S.; Eryavec, G.; Seymour, P.; Lever, A. B. P. *Inorg. Chem.* **1985**, *24*, 1901.

(13) Wayner, D. D. M.; Dannenberg, J. J.; Griller, D. *Chem. Phys. Lett.* **1986**, *131*, 189.

(14) Schiesser, C. H.; Wille, U.; Matsubara, H.; Ryu, I. *Acc. Chem. Res.* **2007**, *40*, 303.

(15) (a) Kharasch, M. S.; Reinmuth, O.; Urry, W. H. *J. Am. Chem. Soc.* **1947**, *69*, 1105. (b) Franz, J. F.; Kraus, W. B.; Zeitler, K. *Chem. Commun.* **2015**, *51*, 8280. (c) Nauth, A. M.; Orejarena Pacheco, J. C.; Pusch, S.; Opatz, T. *Eur. J. Org. Chem.* **2017**, 6966.

(16) He, L.; Pian, J.-X.; Shi, J.-F.; Du, G.-F.; Dai, B. *Tetrahedron* **2014**, *70*, 2400.

(17) Ackermann, L.; Althammer, A. *Angew. Chem. Int. Ed.* **2007**, *46*, 1627.