

Chelation-assisted electrocyclic reactions of 3-alkenyl-2,2'-bipyridines: an efficient method for the synthesis of 5,6-dihydro-1,10-phenanthroline and 1,10-phenanthroline derivatives†

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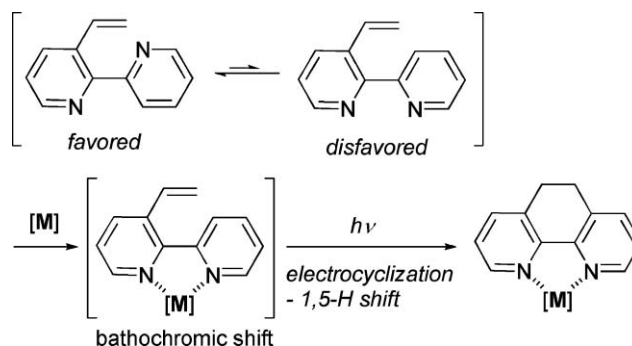
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An efficient method for the synthesis of substituted 5,6-dihydro-1,10-phenanthrolines and 1,10-phenanthrolines has been developed by means of the chelation-assisted photochemical electrocyclic reactions of 3-alkenyl-2,2'-bipyridines.

1,10-Phenanthrolines are some of the most important, widely used chelating ligands in coordination chemistry, and their metal complexes have been used not only as catalysts in organic synthesis but also as component molecules for functional materials and building blocks in supramolecular chemistry.¹ Various methodologies for the synthesis of 1,10-phenanthrolines are known, including the classical Skraup and Friedlander reactions, but many of them are not necessarily useful for substrates bearing labile functionalities, because these methods normally require strongly acidic or basic conditions and high reaction temperatures.² Therefore, it remains desirable to develop efficient methods for the preparation of variously substituted 1,10-phenanthroline derivatives for the effective development of these research areas.

Photochemical electrocyclic cyclization of 6 π -electron systems is highly useful for the construction of fused aromatic systems. In fact, this reaction is often applied to the synthesis of phenanthrene derivatives by using stilbene or vinylbiphenyl derivatives as substrates.³ However, to our knowledge, only one example employing 1,2-bis(3-pyridyl)ethylene is known for the preparation of 1,10-phenanthroline derivatives,^{4,5} and none is known for the electrocyclic reactions of 3-alkenyl-2,2'-bipyridines. In fact, irradiation of a CH₃CN solution of 5,5'-bis(triethylsilyl)-3-alkenyl-2,2'-bipyridine **1a**⁶ using a Xe or low-pressure Hg lamp through a quartz tube at ambient temperature gave none of the desired 5,6-dihydro-1,10-phenanthroline **2a**, even after 10 h, but most of the starting material was recovered. This result is probably due to the fact that the *s-trans* conformation of the bipyridine, which is not suitable for electrocyclic reactions, is more stable than the *s-cis* conformation. We then thought of the possibility of a chelation-assisted electrocyclic reaction of 3-alkenyl-2,2'-bipyridines based on the following two expectations; (1) addition of a metal salt would induce chelate formation with the bipyridine to fix the conformation of the molecule suitably for cyclization (Scheme 1), and (2) formation of a metal chelate would induce a significant bathochromic shift of the absorption band,⁷ which would enable



Scheme 1 Chelation-controlled electrocyclic reaction.

the efficient photoexcitation of the substrate using a standard high pressure Hg lamp without the necessity of using quartz apparatus.

Based on these considerations, the reaction was examined by irradiating a de-gassed CH₃CN solution of a mixture of the bipyridine **1a** and various kinds of metal salt using a Pyrex tube (Table 1). Although the use of LiOTf was not so effective (Table 1, entry 1), the reactions using Mg(OTf)₂, ZnCl₂ and Zn(OTf)₂ were completed in only 1 h to afford 5,6-dihydro-1,10-phenanthroline **2a** in about 70% yield (Table 1, entries 3–5).⁸ Lanthanide triflates, such as Yb(OTf)₃ and Sc(OTf)₃, were effective for this reaction but

Table 1 Screening of the reaction conditions^a

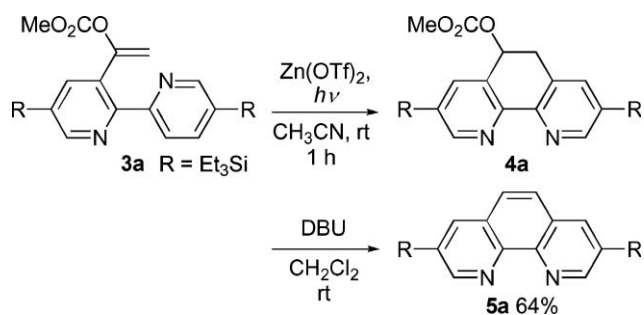
| Entry | [M] | Solvent | Yield (%) |
|----------------|----------------------|---------------------------------|-----------|
| 1 | LiOTf | CH ₃ CN | 15 |
| 2 ^b | CuCl ₂ | CH ₃ CN | 40 |
| 3 | Mg(OTf) ₂ | CH ₃ CN | 72 |
| 4 | ZnCl ₂ | CH ₃ CN | 72 |
| 5 | Zn(OTf) ₂ | CH ₃ CN | 67 |
| 6 | Yb(OTf) ₃ | CH ₃ CN | 56 |
| 7 | Sc(OTf) ₃ | CH ₃ CN | 62 |
| 8 | Zn(OTf) ₂ | Et ₂ O | 26 |
| 9 | Zn(OTf) ₂ | THF | 24 |
| 10 | Zn(OTf) ₂ | CH ₂ Cl ₂ | 49 |
| 11 | Zn(OTf) ₂ | DMF | 41 |
| 12 | Zn(OTf) ₂ | MeOH | 44 |

^a 1 equiv. of metal salt was added. Irradiation was carried out using a 250 W super high pressure Hg lamp through a Pyrex tube in de-gassed solvent. ^b Aromatized 1,10-phenanthroline was obtained in 23% yield.

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Scheme 2 Synthesis of 1,10-phenanthroline derivatives.

gave **2a** in slightly lower yields (Table 1, entries 6 and 7). The addition of CuCl₂ also promoted the desired reaction, albeit the products contained a significant amount of the aromatized product (Table 1, entry 2). Other solvents, such as Et₂O, THF and CH₂Cl₂, were also examined using Zn(OTf)₂; however, 5,6-dihydro-1,10-phenanthrolines **2a** were obtained in low yield. This was probably due to the low solubility of the zinc salt in these solvents, and 3-alkenyl-2,2'-bipyridine **1a** was recovered (Table 1, entries 8–10). The reactions in DMF and MeOH were slightly sluggish and gave **2a** in about 40% yield, along with unidentified mixtures of by-products (Table 1, entries 11 and 12). It should be noted that the absorption maximum of 1 : 1 mixtures of **1a** and Zn(OTf)₂ or ZnCl₂ in CH₃CN were observed at *ca.* 320 nm, which clearly shows that the expected bathochromic shift actually occurred in the presence of metal salts, and that this is the reason why the reaction proceeded using a high pressure Hg lamp and Pyrex apparatus. These features would make the reaction highly practical.

As the desired reaction was found to proceed as expected, we next examined its generality by employing several 3-alkenyl-2,2'-bipyridine derivatives and zinc salts (Table 2).⁹ Substrates

Table 2 Reactions with various 3-alkenyl-2,2'-bipyridines^a

| Entry | Starting material | Product | Yield (%) |
|----------------|-------------------|---------|-----------|
| 1 | | | 63 |
| 2 | | | 66 |
| 3 | | | 63 |
| 4 ^b | | | 66 |

^a R = Et₃Si. Conditions: 1 equiv. Zn(OTf)₂, *hν*, CH₃CN, 1 h, rt.
^b 1 equiv. of ZnCl₂ was used.

substituted not only at the α-position but also at the β-position of the alkenyl moiety were suitable for this electrocyclic reaction to give the corresponding 5,6-dihydro-1,10-phenanthroline derivatives in good yields. Silyl enol ether derivative **1e** could be employed as the substrate, giving an oxygen-functionalized dihydrophenanthroline (Table 2, entry 4).

We next examined the synthesis of 1,10-phenanthroline derivatives.¹⁰ The electrocyclic reaction of alkenyl carbonate **3a**, which was easily accessible from the corresponding ketone, also proceeded smoothly to give 5,6-dihydrophenanthroline **4a**. Next, treatment of crude product **4a** with DBU in CH₂Cl₂ induced the elimination of MeOCOO⁻, giving the desired 1,10-phenanthroline derivative **5a** in good yield in 2 steps (Scheme 2).

Reactions of some representative substrates are summarized in Table 3. Thus, 3-alkenyl-2,2'-bipyridines substituted with Me, Ph, alkynyl and Br groups were converted into the corresponding 1,10-phenanthrolines **5** in good yield. Moreover, the electrocyclic reaction of substrate **3b**, which has a substituent at the β-position of the alkenyl moiety, also proceeded in good yield to produce

Table 3 Reactions with various 3-alkenyl-2,2'-bipyridines bearing a methylcarbonate group on the alkenyl moiety^a

| Entry | Starting material | Product | Yield (%) |
|----------------|-------------------|---------|-----------|
| 1 | | | 68 |
| 2 | | | 59 |
| 3 | | | 72 |
| 4 | | | 59 |
| 5 | | | 74 |
| 6 | | | 70 |
| 7 ^b | | | 69 |

^a Conditions: 1 equiv. of Zn(OTf)₂, *hν*, CH₃CN, 1 h, rt; then DBU, CH₂Cl₂, rt. ^b Desilylation occurred upon treatment with DBU.

5-methyl-1,10-phenanthroline **5b**. In these reactions, the use of ZnCl_2 instead of $\text{Zn}(\text{OTf})_2$ gave the corresponding phenanthrolines in slightly lower yield.

In summary, we have developed an efficient method for the synthesis of substituted 5,6-dihydro-1,10-phenanthrolines and 1,10-phenanthrolines *via* the chelation-assisted photochemical electrocyclic reactions of 3-alkenyl-2,2'-bipyridines. The formation of zinc chelates controls the conformation of the substrate in a desirable manner, and also induces a significant bathochromic shift of the absorption band, which permits efficient excitation of the substrate with a standard high pressure Hg lamp and Pyrex apparatus. As chelation-controlled electrocyclization has scarcely been employed in organic synthesis,^{11,12} the present method offers new possibilities for the efficient synthesis of heterocycles *via* pericyclic reactions.

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- Both $\text{Zn}(\text{OTf})_2$ and ZnCl_2 gave almost the same result in every case.
- We first examined the *in situ*-oxidation of dihydrophenanthroline **2** to the corresponding 1,10-phenanthroline. However, photoirradiation of the reaction mixture under an oxygen atmosphere resulted in a complex mixture, and none of the desired compound was detected.
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