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Synthesis and properties of 2-(2-pyridyl)-1-azaazulene

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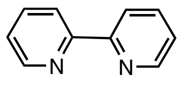
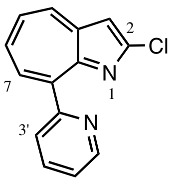
Abstract—The title azaazulene **3** was synthesized either by reaction of tropone with *N*-{(2-pyridyl)acetyl}pyridinium iodide in the presence of ammonium acetate or by palladium-catalyzed cross-coupling between 2-halo-1-azaazulene and 2-substituted pyridine. The compound shows relatively stronger basicity compared with 2,2′-bipyridyl. While **3** showed no emission from the S_1 state but from the S_2 state like azulene does, the protonated species of **3** exhibited emission from the S_1 state. Cationic metal-dependent absorption and emission relating to complexation were also studied.

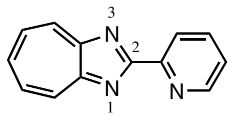
To date, synthetic studies of pyridyl-azaazulene and -diazaazulenes,[1] which can be used as bidentate ligands like 2,2′-bipyridyl,[2] have been limited to two cases reported by Abe et al. and Nakano et al. The former authors prepared 2-chloro-8-(2-pyridyl)-1-azaazulene (**1**)[3] by addition of 2-pyridyllitium to 2-chloro-1-azaazulene and subsequent oxidation, and Nakano and Sunagawa synthesized 2-(2-pyridyl)-1,3-diazaazulene (**2**)[4] by the reaction of 2-methoxy- or 2-chlorotropone with pyridylamidine. However, their basic physical properties have not been disclosed fully and application of **1** to metal complexation is also limited. Abe et al. reported that the reaction of **1** with copper ion yielded the 2:1 complex with a whole shape of the trigonal bi-pyramidal structure but not of a square plane structure probably because of the steric interaction between the 3′- and 7-protons in its planar structure. Indeed, DFT calculations[5] predict the severe interaction in a planar structure of **1**.[6] In this Letter, we describe the synthesis and basic physical properties, including emission property, of the title compound **3** which is expected to behave as a bidentate ligand in a different way from **1**.



2,2′-bipyridyl



1



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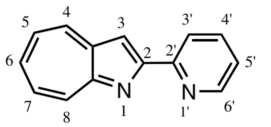

3

The synthesis of **3** was achieved by two methods as shown in Scheme 1. One method is based on the azaazulene synthesis of Sugimura et al.[7] The reaction of tropone (**4**) with the ylide, generated from *N*-{(2-pyridyl)acetyl}pyridinium iodide (**5**),[8] in the presence of ammonium acetate provided **3**. After an exploration of the reaction conditions in this intricate multi-step reaction, the optimal yield of **3** (58%) was realized when refluxed in acetic acid with the aid of 7.5 equiv of ammonium acetate.[10] The other method is a Pd-catalyzed cross-coupling reaction between 2-halo-1-azaazulenes (**6a–c**)[9] and 2-substituted pyridines **7**. Results of the cross-coupling reactions are listed in Table 1. The Suzuki–Miyaura coupling[11] of **6** was examined with

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Keywords: Basicity; UV–vis absorption spectrum; Emission spectrum; Cross-coupling reaction; Metal complexation.

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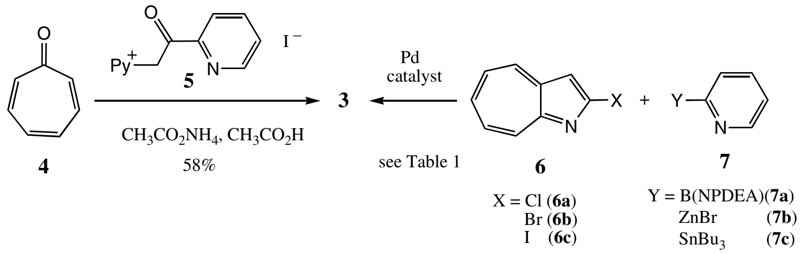
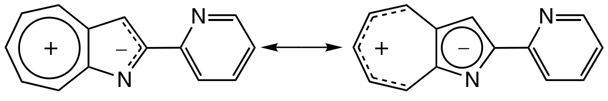


Scheme 1. Synthetic methods of **3**.

2-pyridineboronic acid *N*-phenyldiethanolamine (NPDEA) ester[12] and the yields of **3** were low (entries 1–3). The Negishi coupling using 2-pyridylzinc bromide required a greater amount of the palladium catalyst and resulted in much better yields. While chloro- and bromoazaazulenes, **6a** and **6b**, were not consumed completely even in a longer reaction period (entries 4 and 5), the reaction with iodoazaazulene **6c** proceeded smoothly, providing the highest yield (92%) of **3** (entry 6). The Stille coupling (entries 7–9) with tributylstannylpyridine **7c** completed much faster than the other couplings and provided moderate yields of **3**. In contrast to the other couplings, the Stille coupling with **6c** was hampered by formation of by-products, affording **3** in 14% yield.



3A **3B**

The title compound **3** was isolated as fine red needles after sublimation and was characterized by spectroscopic and combustion analyses. Although allowing a sample of **3** to stand at room temperature under air resulted in a slight change of color from fine to dull red, the sample can be stored under inert gas atmosphere in a refrigerator without any change for at least more than a couple of months. In the UV–vis spectrum in acetonitrile the longest wavelength absorption maximum of **3** was observed at $\lambda_{max} = 512$ nm which showed a bathochromic shift in less polar solvents, suggesting significant contribution of the dipolar resonance forms, **3A** and **3B**, at the ground state. A hypsochromic shift was observed in acidic solutions of **3**. In 50% H_2SO_4 the maximum was observed at $\lambda_{max} = 429$ nm with a hyperchromic effect and thus the solution appeared in yellow. Mono- and diprotonated species of **3** with hydrogen bromide were also isolated.[13] The pK_a values of the salts were determined by pH measurements of the solutions prepared by mixing **3** with arbitrary amounts of these salts[14,15] to be 2.42 ± 0.12 (pK_{a2}) for the proton dissociation of $\mathbf{3}{\cdot}2H^+$ and 6.02 ± 0.06 (pK_{a1}) for the dissociation of $\mathbf{3}{\cdot}H^+$ (Table 2). Both values are greater than the reported values of 2,2′-pyridyl;[15–17] *id est*, both the imino groups of **3** are stronger bases than those of 2,2′-pyridyl. The major reason can be drawn from the stabilized resonance structures[18] of **3A** and **3B** with the negatively charged five-membered ring. The pK_{a1} value of **3** is slightly less than that of 2-phenyl-1-azaazulene (**8**).[8,19] The phenomenon is rationalized by the fact that a pyridyl group shows a greater electron-withdrawing resonance effect than a phenyl group does. Therefore, the monoprotonated species $\mathbf{3}{\cdot}H^+$ is thermodynamically destabilized by the pyridyl group much more than $\mathbf{8}{\cdot}H^+$ is by the phenyl group.[20]

An outstanding feature of physical properties of **3** is its pH-dependent emission spectrum at room temperature. The free base **3** in acetonitrile showed an emission, assumed to be $S_2 \rightarrow S_0$ relaxation, at 434 nm upon excitation of 368 nm ($\Phi = 5.26 \times 10^{-3}$)[21] and no emission upon excitation of the longest wavelength maximum of 512 nm (Fig. 1),[22] similarly seen in the case of azulene.[23] On the other hand, the diprotonated species $\mathbf{3}{\cdot}2H^+$ in 50% H_2SO_4 exhibited an emission of 484 nm upon exci-

Table 1. Results of cross-coupling reactions of 2-halo-1-azaazulene **6**

Entry	6	7	Reaction conditions	Yield (%) of 3[a]	Recovery of 6
1	**6a**	**7a**[b]	5% $Pd(PPh_3)_2Cl_2$, CuI, Cs_2CO_3, THF, refl, 4 h	0	95
2	**6b**	**7a**[b]	5% $Pd(PPh_3)_2Cl_2$, CuI, Cs_2CO_3, THF, refl, 4 h	20 (22)	7
3	**6c**	**7a**[b]	5% $Pd(PPh_3)_2Cl_2$, CuI, Cs_2CO_3, THF, refl, 4 h	25	0
4	**6a**	**7b**[c]	10% $Pd(PPh_3)_4$, THF, 60 °C, 48 h	47 (68)	32
5	**6b**	**7b**[c]	10% $Pd(PPh_3)_4$, THF, 60 °C, 48 h	51(80)	36
6	**6c**	**7b**[c]	10% $Pd(PPh_3)_4$, THF, 60 °C, 48 h	92	0
7	**6a**	**7c**[d]	5% $Pd(PPh_3)_4$, CuO, DMF, 120 °C, 3 h	44	0
8	**6b**	**7c**[d]	5% $Pd(PPh_3)_4$, CuO, DMF, 120 °C, 3 h	47	0
9	**6c**	**7c**[d]	5% $Pd(PPh_3)_4$, CuO, DMF, 120 °C, 3 h	14[ee]	0

[a] The yields in parentheses are based on the consumed starting material.

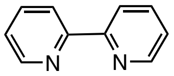
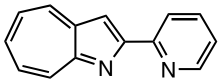
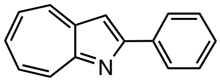
[b] An excess of the reagent (3 equiv) were used.

[c] An excess of the reagent (2.7 equiv) were used.

[d] A slightly excess of the reagent (1.2 equiv) was used.

[e] The desired product **3** was obtained with a mixture of by-products whose structures were not clarified yet.

Table 2. The pK_a values of 2,2′-bipyridyl, **3**, and **8**

Amines	pK_{a1}	pK_{a2}
 2,2'-bipyridyl	4.34[a] 4.12[b]	−0.20[a] −0.52[c]
 **3**	6.02[d]	2.42[d]
 **8**	6.81[d]	

[a] Taken from Ref. 16.
[b] Taken from Ref. 15.
[c] Taken from Ref. 17.
[d] Measured in this study.

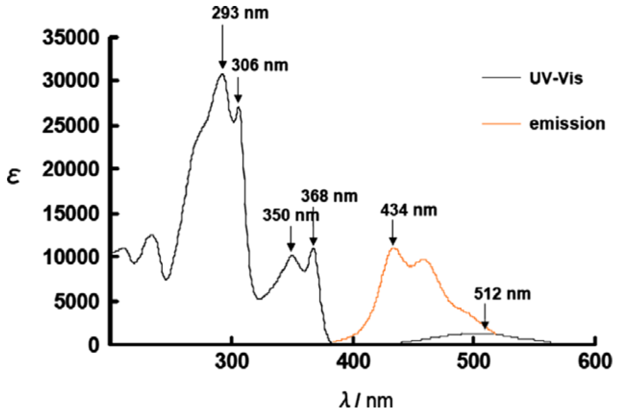


Figure 1. The UV–vis absorption and normalized emission spectra of **3** in CH_3CN.

tation of the longest wavelength maximum of 429 nm ($\Phi = 4.10 \times 10^{-4}$),[21] assumed to be $S_1 \rightarrow S_0$ relaxation (Fig. 2).[24] Noteworthily we report at a first time that 1-azaalulene shows a clear emission upon excitation of the longest wavelength absorption in acidic media at room temperature,[25] apart from its relatively low quantum yield.

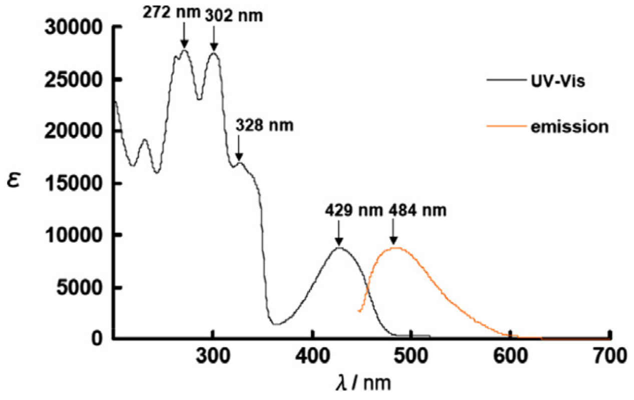


Figure 2. The UV–vis absorption and normalized emission spectra of **3** in 50% H_2SO_4.

The absorption and emission spectra of **3** were also found dependent on a metal cation present in a solution. While the longest wavelength absorption maximum of **3** in the presence of a large excess amount of $NaClO_4$ in acetonitrile indicated a slight hypsochromic shift of 14 nm, the maximum of **3** in the presence of the same amount of $Mg(ClO_4)_2$ showed a greater hypsochromic shift of 34 nm with a greater coefficient. In addition, while an emission at 543 nm was observed upon excitation of the longest wavelength absorption maximum of 478 nm in the presence of Mg^{2+} ion, no emissions was observed from the S_1 state in the presence of Na^+ ion but an emission from the S_2 state as seen in the free base (Figs. 3 and 4). These results suggest that **3** forms a rigid complex with Mg^{2+} ion, probably in a tetrahedral shape,[26] but not with Na^+ ion.

As a summary, we have synthesized a novel 1-azaazulene derivative, 2-(2-pyridyl)-1-azaazulene (**3**), either by reaction of tropone with *N*-{(2-pyridyl)acetyl}pyridinium iodide with the aid of ammonium acetate or by the cross-couplings between 2-halo-1-azaazulene and 2-substituted pyridine. The compound exhibits relatively stronger basicity and it should be emphasized that **3** showed the pH and cationic metal-dependent emission

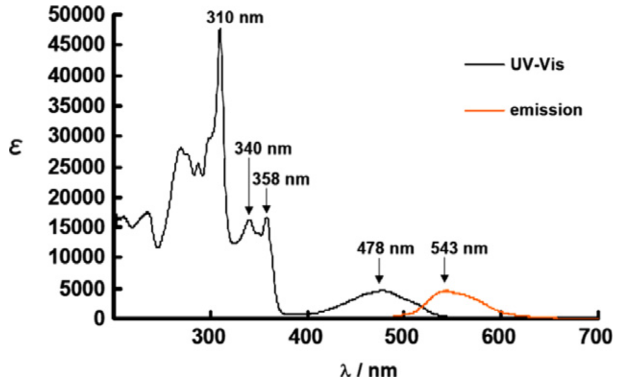


Figure 3. The UV–vis absorption and normalized emission spectra of **3** in the presence of magnesium perchlorate (1000 equiv to **3**).

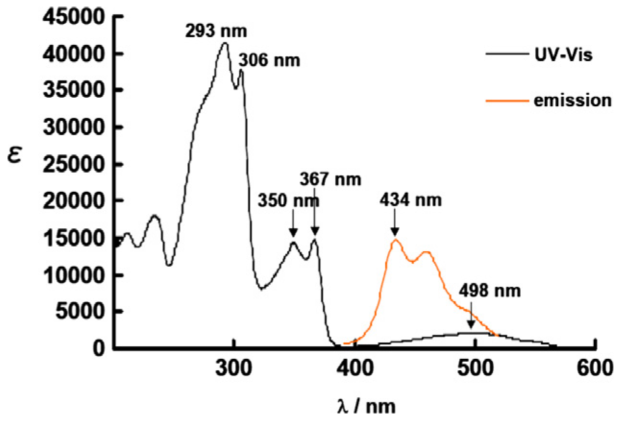


Figure 4. The UV–vis absorption and normalized emission spectra of **3** in the presence of sodium perchlorate (1000 equiv to **3**).

spectra. Further a study on chelation of this novel ligand with various metal ions including transition metals is under progress.

Acknowledgments

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6. Total energy difference between the planar structure with the two nitrogen atoms at the same side and the most stable structure with a dihedral angle through 1′–2′–8–8a of 148.8° is 0.21619 a.u (13.521 kcal mol^{-1}). The distance between the 3′ and 7 protons in the planar structure is 1.756 Å (175.6 pm).
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25. We also found that 2-phenyl-1-azaazulene (**8**) behaved similarly.

26. The Job plot of **3** with $Mg(ClO_4)_2$ using absorption changes indicated the binding mode of two molecules of **3** to one of Mg^{2+} ion.