HETEROCYCLES, Vol. 86, No. 2, 2012, pp. 1129 - 1134. © 2012 The Japan Institute of Heterocyclic Chemistry
Received, 26th June, 2012, Accepted, 25th October, 2012, Published online, 12th November, 2012
DOI: 10.3987/COM-12-S(N)62

HYDROGEN BONDING INDUCED HIGHLY SELECTIVE ISOMERIZATION OF AN OLEFIN HAVING HETEROAROMATIC RINGS

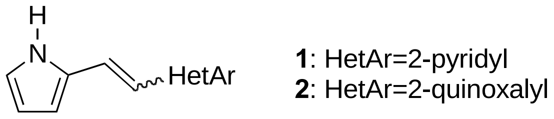
Takuya Kobayashi and Tatsuo Arai*

Graduate School of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Ibaraki 305-8571, Japan

Abstract – Heteroaromatic compounds having two different isomerization parts in the molecule containing nitrogen at the aromatic ring have been synthesized and their photoisomerization and fluorescence properties have been examined.

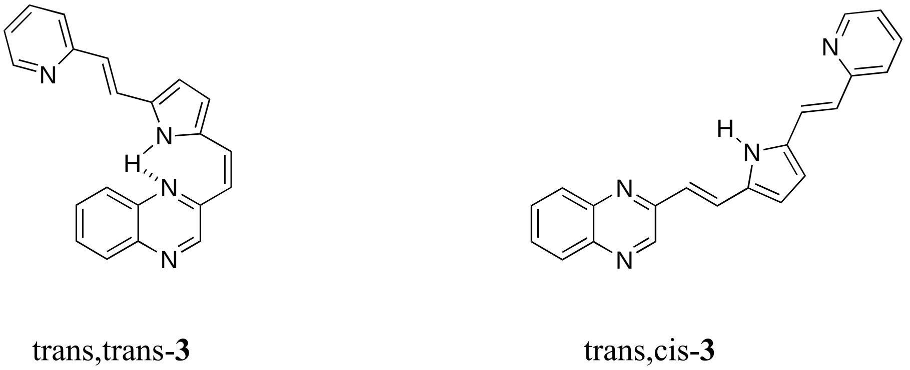
INTRODUCTION

Much attention has been focused on the nitrogen containing aromatic compounds from the fundamental point of view as well as application to optical materials and medicinal compounds.[1,2] The reason for the increase of active interest and importance for the research in these compounds might be the characteristic nature and reactivity of these compounds. Especially, nitrogen containing aromatic compound exhibited characteristic properties in the excited state such as intramolecular hydrogen atom transfer induced highly selective *trans*-to-*cis* isomerization and unusual fluorescence emission at considerably longer wavelength region. For example, in the case of **1**,[3] only *cis*-isomer forms intramolecular hydrogen bonding between pyrrole ring and pyridine ring which is confirmed by the highly down field shift of the NH proton of the pyrrole ring. Due to this intramolecular hydrogen bonding, **1** exhibited one-way *trans*-to-*cis* photoisomerization in the excited singlet state. That is, while *trans*-**1** underwent photoisomerization to *cis*-**1**, *cis*-**1** did not give *trans*-**1**. However, *cis*-**1** underwent intramolecular hydrogen atom transfer to give the tautomer (*cis*-**1** tautomer), which is revealed by the observation of the fluorescence at unexpectedly longer wavelength region peaking at 570nm. Compound 2 exhibited similar photochemical properties.



Scheme 1. Chemical structures of **1** and **2**

In the course of our study on the effect of hydrogen bonding on photochemical behavior of olefinic compounds, we are interested in the compounds with pyrrole ring and two hetroaromatic rings capable to form intramolecular hydrogen bonding with pyrrole NH, to know the factor to control the photoisomerization direction among the two different isomerization parts. We wish to report here the photochemical and spectroscopic properties of potentially hydrogen bonding compounds by introduction of two different N-containing aromatic ring, pyridine and quinoxaline ring connecting by C=C double bond at both ends of pyrrole ring, **3**.



Scheme 2. Chemical structure of *trans,trans*-**3** and *trans,cis*-**3**

RESULTS AND DISCUSSION

Figure 1 shows absorption spectra of *trans,trans*-**3** having absorption maximum at 456 nm and *trans*,*cis*-**3** having absorption maximun at 483 nm. As is usual for the hydrogen bonded compounds, but is unusual for aromatic olefins such as stilbene, the *trans,cis*-**3** shows absorption at longer wavelength probably due to the intramolecular hydrogen bonding influencing some kind of increase of conjugation. These experimental results are in accordance with the previous findings for **1**, and it is cleared that **3** shows absorption at the lowest energy region among some pyrrolylethenes reported previously.[3-8]

On irradiation of *trans,trans*-**3** in benzene at 498 nm, which is the isosbestic point, the absorption maximum of *trans,trans*-**3** decreased and that of the isomer increased.(Figure 2).

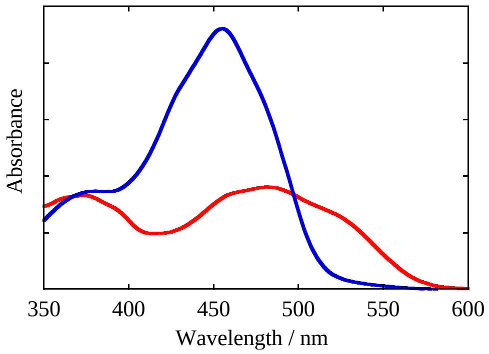


Figure 1. Absorption spectra of *trans*,*trans*-3 (blue) and *trans,cis*-3 (red) in benzene

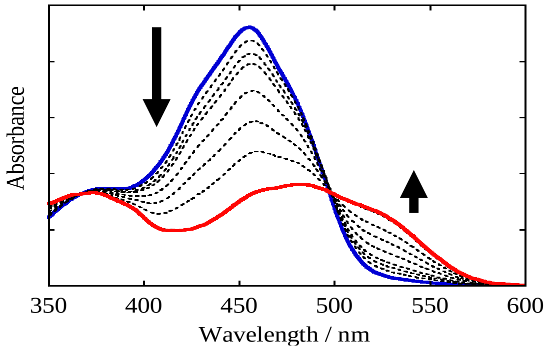


Figure 2. The change of the absorption spectra from *trans,trans*-3 to the photostationary state on irradiation at 498 nm in benzene

In order to confirm conformation of the isomer, the ^{1}H NMR analyses have been performed. As shown in Figure 3 proton signals changed with irradiation time at 365 nm and this peak change indicates the production of the *cis* isomer at quinoxaline side instead of pyridine side. Furthermore, no more isomerization to the *cis* isomer at the pyridine side took place. Thus, in compound **3** having two possible *cis* conformation, only quinoxaline side isomerized to the *cis* conformation to give *trans,cis*-**3**.

The isomer ratio of ([*trans,trans*-**3**]/[*trans,cis*-**3**]) at the photostationary state exciting at the isosbestic point 498 nm was determined to be ([*trans,trans*-**3**]/[*trans,cis*-**3**])pss = 3/97. This result indicates that the photoisomerization from *trans,trans*-**3** to *trans,cis*-**3** is much more efficient than that of the reverse process: the quantum yield of *trans,trans*-**3**-to-*trans,cis*-**3** photoisomeriation is more than 30 times more efficient than that of *trans,cis*-**3**-to-*trans,trans*-**3** photoisomerization.

The results of the preferential photoisomerization to give *trans,cis*-**3** may indicate that the isomerization reactivity is controlled by the size of the aromatic ring, which may be related to the energetic situation of the isomerization processes to the quinoxaline side or pyridine side; because of the larger aromatic ring for quinoxaline ring than that of pyridine ring, the energy curve favors to the isomerization reaction to the quinoxaline side. These discussions are supported by the energy in the singlet excited state. That is, if one considers *trans,trans*-**3** composed of two olefinic chromophore of **1** and **2**, the excited state energy of **2** has the lower energy than that of **1** (E_S = 76 kcal/mol, E_S = 65 kcal/mol for **1** and **2**, respectively).[3,8] Therefore, the reactivity of *trans,trans*-**3** in the singlet excited state (E_S =57 kcal/mol for **3**) may be dominated at the olefinic part of **2** containing quinoxaline ring, resulting in the selective photoisomerization mentioned above.

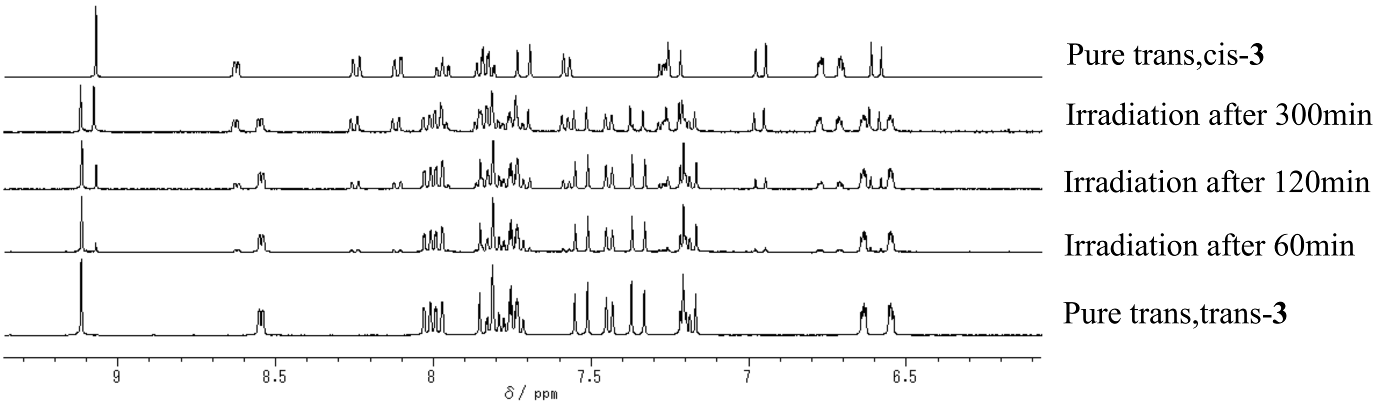


Figure 3. The change of the ^{1}H NMR from *trans,trans*-**3** to the on irradiation at 365 nm in DMSO

Figure 4 shows the fluorescence spectra of *trans,trans*-**3** in various solvents. As clearly shown in this figure, the fluorescence spectra shifted to the longer wavelength region and the vibrational structure disappeared with increasing solvent polarity. This results can be explained by the charge transfer character of *trans,trans*-**3** in the excited singlet state by the electron rich pyrrole ring to the electron deficient quinoxaline ring. The fluorescence quantum yield of *trans,trans*-**3** is relatively high in non-polar and polar solvent from 0.14 to 0.27.

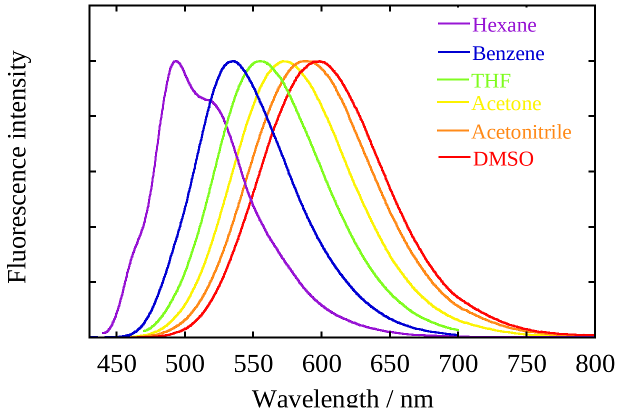


Figure 4. Fluorescence spectra of *trans,trans*-**3** in various solvents

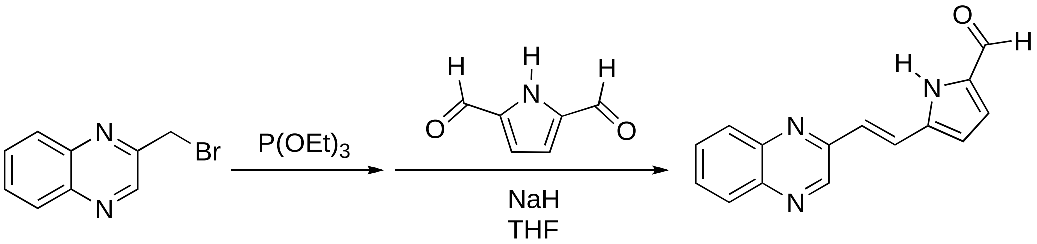
Table 1. Fluorescence properties of *trans,trans*-**3**

Solvent	λ_{UV} /nm	λ_{FL} / nm	Stokes shift / cm^{-1}	Φ_f
Hexane	442	493	2340	0.16
Benzene	456	535	3240	0.24
THF	454	565	3860	0.27
Acetone	451	574	4760	0.25
Acetonitile	446	589	5440	0.24
DMSO	464	598	4920	0.14

In conclusion, heteroaromatic compounds having two different isomerization parts in the molecule containing nitrogen at the aromatic ring have been synthesized and their photoisomerization and fluorescence properties have been examined. Among the obtained results, specific photoisomerization from the *trans,trans* isomer to the *trans,cis* isomer with larger conjugation moiety exclusively took place. Furthermore, the intramolecular hydrogen bonding highly inhibited the isomerization from *trans,cis* isomer to *trans,trans* isomer. Moreover, the *trans,trans* isomer exhibited considerably high fluorescence quantum yield in various solvent with different maximum wavelength sifting to longer wavelength with increasing solvent polarity.

EXPERIMENTAL

Materials

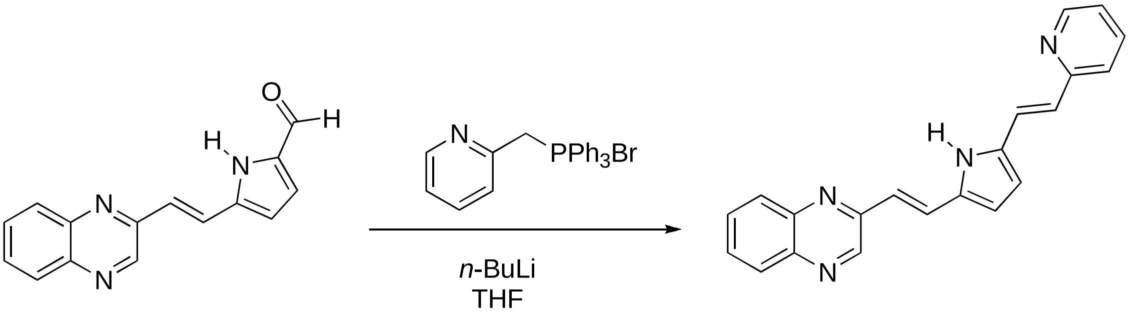


5-((*E*)-2-(Quinoxalin-3-yl)vinyl)-1*H*-pyrrole-2-carbaldehyde

A mixture of 2-bromomethyl quinoxaline (2.51 g, 11.3 mmol) and triethylphosphite (8.72 g, 52.5 mmol) was refluxed for 12 h. After cooling, the excess triethylphosphite was removed *in vacuo* to leave red residue. This crude product diethyl (quinoxalin-2-ylmethyl)phosphonate was used in the next step without further purification.

To a mixture of sodium hydride (0.665 g, 27.7 mmol) and 2,5-diformylpyrrole (1.35 g, 11.0 mmol) in dry THF (60 mL) was added diethyl (quinoxaline-2-ylmethyl)phosphonate dissolved in dry THF (10 mL), and the mixture was stirred at 80 °C for 1.5 h, after which time the reaction was quenched by additional of water (5 mL). The solvent was evaporated and the residue was dissolved in $CHCl_3$ (200 mL), washed with brine, dried over sodium sulfate, filtered and evaporated. The residue was purified by silica gel column chromatography [eluent: $CHCl_3$/EtOAc (4:1)] to give the desired product as a red solid (1.15 g, 42 %).

^{1}H NMR (400 MHz, $CDCl_3$): δ 10.23 (s, 1H), 9.57 (s, 1H), 8.97 (s, 1H), 8.09-8.04 (m, 2H), 7.83-7.96 (m, 3H), 7.35 (d, J = 16.2 Hz, 1H), 7.04-7.03 (m, 1H), 6.70-6.68 (m, 1H).



2-((*E*)-2-(Pyridin-3-yl)vinyl)-5-((*E*)-2-(quinoxalin-3-yl)vinyl)-1*H*-pyrrole (**3**)

n-BuLi (0.30 ml of a 2.6 M hexane solution, 0.78 mmol) was added slowly to a suspension of 2-methylpyridinephosphonium bromide (289 mg, 0.667 mmol) in dry THF (15 mL) at -78 °C under nitrogen atomosphere. After complete addition, the reaction mixture was brought to room temperature and was stirred for 0.5 h. Then, the reaction mixture was cooled to -78 °C and added 5-((*E*)-2-(quinoxalin-3-yl)vinyl)-1*H*-pyrrole-2-carbaldehyde (254 mg, 1.02 mmol) dissolved in dry THF (10 mL), and the reaction mixture was stirred for 2 h, after which time the reaction was quenched by additional of EtOAc (10 mL) and water (10 mL). The solvent was evaporated and the residue was dissolved in EtOAc (50 mL × 2), washed with brine, dried over sodium sulfate, filtered and evaporated. The residue was purified by silica gel column chromatography [eluent: Hexane/EtOAc (2:1)] to give the desired product as a red solid (208 mg, 63 %).

^{1}H NMR (400MHz, DMSO): δ 11.75 (brs, 1H), 9.11 (s, 1H), 8.54 (d, J = 4 .0 Hz, 1H), 7.96-8.03 (m, 2H), 7.66-7.83 (dm, J = 7.1 Hz, 3H), 7.83 (d, J = 16.1 Hz, 1H), 7.53 (d, J = 16.3 Hz, 1H), 7.43 (d, J = 7.1 Hz, 1H), 7.34 (d, J = 16.3 Hz, 1H), 7.17-7.20 (m, 1H), 7.18 (d, J = 16.1 Hz, 1H), 6.61-6.63 (m, 1H), 6.54-6.56 (m, 1H). Anal. Caled for $C_{21}H_{17}N_3$: C, 81.00; H, 5.50; N, 13.49. Found: C, 80.77; H, 5.68; N, 13.22. IR (KBr disk): 3427, 3346, 1638 cm^{-1}. Mp: 152 °C.

Apparatus

Absorption and fluorescence spectra were measured on a Shimadzu UV-1600 and on a Hitachi F-4500 fluorescence spectrometer, respectively. All solvents of spectral grade for spectroscopy were purchased and used without further purification. All measurements were carried out at room temperature under Ar. The concentration of solution for spectroscopy was adjusted so that the absorption maximum at the excitation wavelength was 0.1 for each sample. Fluorescence quantum yields were determined relative to anthracene (Φ_f = 0.27 in ethanol). ^{1}H NMR spectra in $CDCl_3$ or DMSO-d_6 with TMS as an internal standard were measured on a 400 MHz NMR spectrometer, AV-400 (Bruker).

ACKNOWLEDGEMENTS

This work was supported by a Grant-in-Aid for Scientific Research in a Priority Area "New Frontiers in Photochromism" (No. 471) and a Grant-in-Aid for Scientific Research (B) (No. 23350075) from the Ministry of Education, Culture, Sports, Science, and Technology (MEXT), Japan.

REFERENCES

1. S. J. Evenson, M. J. Mumm, K. I. Pokhodnya, and S. C. Rasmussen, *Macromolecules*, 2011, **44**, 835.
2. A. Gangjee, O. Adair, and S. F. Queener, *J. Med. Chem.*, 1999, **42**, 2447.
3. M. Obi, H. Sakuragi, and T. Arai, *Chem. Lett.*, 1998, 169.
4. F. D. Lewis, B. A. Yoon, T. Arai, T. Iwasaki, and K. Tokumaru, *J. Am. Chem. Soc.*, 1995, **117**, 3029.
5. Y. Yang and T. Arai, *Tetrahedron Lett.*, 1998, **39**, 2617.
6. T. Arai, M. Moriyama, and K. Tokumaru, *J. Am. Chem. Soc.*, 1994, **116**, 3171.
7. M. Ikegami and T. Arai, *J. Chem. Soc., Perkin Trans. 2*, 2002, 342.
8. K. Kudo, A. Momotake, Y. Kanna, Y. Nishimura, and T. Arai, *Chem. Commun.*, 2011, **47**, 3867.