EFFECT OF NITROGEN POSITION ON EXCITED STATE PROPERTIES OF 1-(9-ANTHRYL)-2-(n-QUINOLINYL)ETHENES

Eun Ju Shin

Department of Chemistry, Sunchon National University, Sunchon, Chonnam 540-742, Korea

Abstract – The fluorescence properties and photoisomerization behavior of 1-(9-anthryl)-2-(n-quinolinyl)ethene (n-AQE, n=2-4) have been investigated in various solvents. *t*-3-AQE is strongly fluorescent, but does not accomplish photoisomerization, similar to parent hydrocarbon compound, *t*-1-(9-anthryl)-2-phenylethene (*t*-9-APE) or *t*-1-(9-anthryl)-2-(1-naphthyl)ethene (*t*-1-ANE). Fluorescence and photoisomerization of *t*-2-AQE and *t*-4-AQE are strongly affected by solvent polarity. Dependence of fluorescence quantum yield on the solvent polarity is moderate for *t*-2-AQE and large for *t*-4-AQE. In nonpolar solvent (in *n*-hexane), they exhibit relatively strong fluorescence, but do not isomerize to cis isomer on irradiation, even if inefficient isomerization is observed for *t*-4-AQE. However, as solvent polarity increases, their fluorescences become weak with efficient photoisomerization to corresponding cis isomer. Intramolecular charge-transfer excited state is presumed to contribute to photoisomerization. The S_1 decay parameters were found to be solvent-dependent due to the charge-transfer character of lowest S_1 state. In polar solvents, the activation barrier to twisting is reduced enhancing the isomerization of *t*-2-AQE and *t*-4-AQE in the singlet manifold.
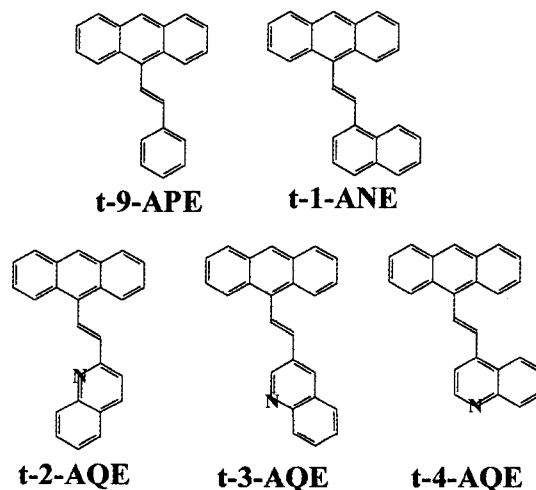
INTRODUCTION

Photochemical *cis-trans* isomerization of stilbene and related 1,2-diarylethenes has long been investigated.[1-5] Photoisomerization of stilbene and their analogues has been proven to proceed mutually between trans and cis isomers via an activated internal rotation in the excited singlet manifold. Recently, n-APEs (n=1, 2, and 9) have been extensively studied because it belongs to a family of 1,2-diarylethylenes that exhibits one way *cis* → *trans* adiabatic photoisomerization.[6-8] The excited-state properties of 1-(n-anthryl)-2-phenylethenes (n-APEs, with n=1, 2, and 9) have attracted much attention because they accomplish efficient *cis*→ *trans* photoisomerization, but do not undergo reverse *trans* → *cis* photoisomerization.[9-15] The energy barrier to twisting is too high for *t*-9-APE to undergo *trans* → *cis* photoisomerization. The excitation energy is extensively localized in the large anthracene moiety so that the transoid geometry corresponds to energy minima in the excited potential energy surface. Interestingly, 9-APE derivatives bearing polar substituents in the para position of the styryl group are known to undergo *trans* → *cis* photoisomerization due to the lowering of the torsional barrier for twisting in the singlet manifold via the intramolecular charge transfer processes, especially in polar solvent.[16-20]

The spectroscopic state properties of some pyridyl[21,22] and pyrazinyl derivatives[23] of 9-APE in the excited state have been previously investigated. As reported in our previous reports, 1-(9-anthryl)-2-(n-pyridyl)ethenes (n-APyE, n=2 or 4),[22] mono-aza analogues of 9-APE, show efficient trans → cis photoisomerization in polar solvent, and 1-(9-anthryl)-2-pyrazinylethene (APzE),[23] a di-aza analogue of 9-APE, exhibits trans → cis photoisomerization even in nonpolar solvent.

This report aims to extend our study to various quinolinyl derivatives containing two polycyclic aryl groups and consequently to correlate the photophysical properties and photoisomerization behavior of 1-(9-anthryl)-2-arylethenes with

t-9-APE   t-1-ANE

t-2-AQE   t-3-AQE   t-4-AQE

Scheme 1

Phone: 0661-750-3635   FAX: 0661-750-3608
e-mail: ejs@sunchon.ac.kr

the size and aza substitution of aryl groups. The present work deals with the properties of the excited state of trans-1-(9-anthryl)-2-(2-quinolinyl)ethene(t-2-AQE), t-3-AQE, and t-4-AQE using steady state emission spectroscopy and photochemical behavior.

MATERIALS AND METHODS

Materials   For spectroscopic measurements and photochemical reactions, n-hexane, tetrahydrofuran (THF), ethyl acetate (EtOAc), acetonitrile (CH_3CN), and methanol (MeOH) of HPLC grade (Merck) were used. Dichloromethane (CH_2Cl_2) and toluene are freshly distilled from P_2O_5 and CaH_2, respectively. All other chemicals are used without further purification after purchase.

Synthesis   The synthesis of n-AQE was accomplished by Wittig reaction between 9-anthrylmethyltriphenylphosphonium bromide and n-quinolinecarboxaldehyde. In dimethyl sulfoxide (50 ml) solution of 9-anthrylmethyltriphenylphosphonium bromide (1.33 g, 2.5 mmol) and n-quinolinecarboxaldehyde(n=2-4, 0.31 g, 2 mmol), sodium methoxide (0.14 g, 2.5 mmol) was added and stirred at 80 °C for 5 hrs. The resulting mixture was poured into distilled water and extracted three times with ethyl ether. The combined ether layer was rinsed several times with distilled water and dried with anhydrous magnesium sulfate. The solution was concentrated in *vacuo* and purified with column chromatography (silica gel) using hexane/ethyl acetate=10/1 (v/v) as an eluent. The first fraction was triphenylphosphine oxide (Ph_3PO). Trans- and cis-isomers were eluted in the second and third fraction, respectively. Typically, t-2-AQE (136.4 mg, 0.4 mmol) and c-2-AQE (160 mg, 0.5 mmol) were obtained in 20 and 25% yields, respectively. Spectroscopic data of t- and c-2-AQE were reported elsewhere.[24]

t-3-AQE (bright yellow solid); IR: 1615, 1488, 1321, 887, 850, 737 cm⁻¹. ¹H-NMR ($CDCl_3$): 7.14 (1H, d, J=16.5 Hz, H10), 7.49-7.52 (4H, m, H2′, 3′, 6′, 7′), 7.62-7.69(1H, m, H6), 7.78-7.83 (1H, m, H7), 7.94-7.96 (1H, m, H5), 8.02-8.07 (2H, m, H4′, 5′), 8.53 (1H, d, J=16.5 Hz, H9), 8.33-8.38 (3H, m, H1′, 8′, 8), 8.44-8.47 (2H, m, H4, 10′), 9.34 (1H, s, H2).

t-4-AQE (bright yellow solid); IR: 1619, 1581, 1443, 886, 849, 731 cm⁻¹. ¹H-NMR ($CDCl_3$): 7.51-7.57 (4H, m, H2′, 3′, 6′, 7′), 7.75-7.77 (1H, m, H6), 7.81-7.87 (3H, m, H3, 5, 7), 8.06-8.11 (2H, m, H4′, 5′), 8.26 (1H, d, J=14.1 Hz, H10), 8.32-8.39 (3H, m, H1′, 8′, 8), 8.52 (1H, s, H10′), 9.04 (1H, d, J=14.1 Hz, H9), 9.21 (1H, d, J=4.2 Hz, H2).

Spectroscopic and photochemical measurements   ¹H-NMR spectra were measured on 300 MHz Varian UNITY plus 300 spectrometer in chloroform-d_1. IR spectra were obtained in KBr pellets on Midac Prospect-IR spectrometer. Absorption spectra were recorded on a Hitachi U-3210 spectrophotometer. Steady state emission spectra were recorded on a SLM-AMINCO AB2 luminescence spectrometer. HPLC data are accom-
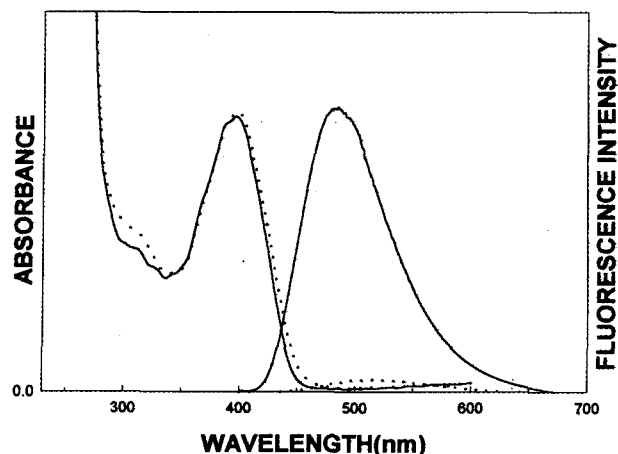

Figure 1. Absorption (left) and fluorescence (right) spectra of t-2-AQE in hexane (solid line) and methanol (dotted line) at room temperature.

plished using Waters Nova-Pak C18 analytical column on a HPLC system equipped with Waters 510 pump and Young-In M720 absorbance detector. Experimental details for measurements of quantum yields of fluorescence and photoisomerization were described previously.[22]

RESULTS AND DISCUSSION

The absorption spectra of t-2-AQE, t-3-AQE, and t-4-AQE in n-hexane and acetonitrile are represented in Figures 1-3, respectively. The absorption spectra of all three isomers are broad and the absorption maxima are similar. The absorption maxima in n-hexane are 394 nm (ε=14,500) for t-2-AQE, 391 nm (ε=8,000) for t-3-AQE, and 388 nm (ε=9,200) for t-4-AQE. However, the absorption spectrum of t-4-AQE is somewhat different in shape and shows characteristic second intense absorption band around 320 nm. In Tables 1-3, the absorption maxima of t-2-AQE, t-3-AQE, and t-4-AQE in the solvents of various polarity are represented, respectively, along with some photophysical and photochemical properties. Those appear to be insensitive to the medium. Absorption spectra of t-n-AQE are very similar to those of 9-APE (1-(9-anthryl)-2-phenylethene)[9-15] and 1-ANE (1-(9-anthryl)-2-(1-naphthyl)ethene).[13] The first intense absorption band of t-2-AQE is placed at 394 nm corresponding to the band at 388 nm of t-9-APE and t-1-ANE in n-hexane.

Figures 1-3 also show fluorescence spectra of t-2-AQE, t-3-AQE, and t-4-AQE in n-hexane and methanol. Fluorescence spectra of all three t-n-AQE in n-hexane at room temperature were very similar and structureless, but fluorescence maximum of t-4-AQE (500 nm) is longer than those of t-2-AQE (483 nm) and t-3-AQE (482 nm). Fluorescence properties of t-2-AQE and t-4-AQE are strongly solvent-dependent. Fluorescence of t-2-AQE and t-4-AQE in methanol is pronouncedly red-shifted with respect to that in n-hexane. Flu-

orescence of *t*-4-AQE is more solvent-dependent than that of *t*-2-AQE. Specially, fluorescence of *t*-4-AQE in methanol is too weak to measure with usual technique. As shown in Table 1, fluorescence maximum of *t*-2-AQE is red-shifted and fluorescence quantum yield is markedly decreased with increasing the solvent polarity. As shown in Tables 1-3, fluorescence maxima (λ_f) and quantum yields (Φ_f) of *t*-n-AQE except *t*-3-AQE are strongly affected by solvent polarity in contrast to Φ_f of the parent *t*-9-APE which is independent of solvent polarity.[17] The fluorescence wavelength of *t*-2-AQE is shifted from 483 nm in *n*-hexane to 518 nm in methanol. For *t*-4-AQE, λ_f are 500 and 530 nm in *n*-hexane and methanol, respectively. In case of *t*-3-AQE, 482 and 502 nm in *n*-hexane and methanol, respectively. As solvent polarity increases, λ_f and Φ_f of those are markedly red-shifted and reduced, respectively. This phenomenon is more pronounced for t-4-AQE which has more polar charge transfer character. Fluorescence of *t*-4-AQE (Table 3) is more rapidly weakened than that of *t*-2-AQE with the high solvent polarity. Lower fluorescence quantum yield of *t*-4-AQE than that of *t*-2-AQE reflect the formation of more stable charge transfer state which lower the barrier twisting around ethenic bond. As in the case of other aza derivatives of 9-APE, for *t*-2-AQE and *t*-4-AQE the intramolecular charge transfer is likely to be responsible for the decrease of the fluorescence yield in polar solvents. As the solvent polarity is increased, the twisted state on the excited energy surface being of zwitterionic character is more stabilized through the intramolecular charge transfer thereby the photoisomerization from either trans or cis side becomes more feasible, thus fluorescence efficiency is decreased.

The fluorescence quantum yield of *t*-2-AQE is reduced from 0.41 in n-hexane to 0.02 in methanol. For *t*-4-AQE, Φ_f are 0.14 and 0.004 in n-hexane and methanol, respectively. Φ_f of *t*-2-AQE is highest among three *t*-n-AQE and Φ_f of *t*-4-AQE is lowest in *n*-hexane. As solvent polarity increases,

Φ_f of *t*-2-AQE and *t*-4-AQE decrease while Φ_f of *t*-3-AQE is nearly unchanged. As shown in Tables 1-3, Φ_f of *t*-4-AQE is more rapidly reduced than that of corresponding 2-isomers as increasing the solvent polarity.

The fluorescence wavelength and Φ_f of *t*-3-AQE are nearly unaffected by the solvent polarity because lone pair electron on nitrogen atom of meta position cannot effectively delocalized in aromatic ring π system[3], and thus the excited state property seems to be similar to that of parent 9-APE. Similar phenomenon was observed in the case of *t*-n-APyE(*t*-1-(9-anthryl)-2-(n-pyridyl)ethene)[22] and *t*-n-styrylpyridines.[14]

The quantum yields of *trans* → *cis* photoisomerization($\Phi_{t \to c}$) of *t*-2-AQE, *t*-3-AQE, and *t*-4-AQE upon 366 nm irradiation in solvents of a wide range of polarity are represented in Table 1-3, respectively. In *n*-hexane, all three *t*-n-AQE carry out very inefficient *t* → *c* photoisomerization like parent 9-APE[9-15] and *t*-n-APyE (n=2-4),[22] even if *t*-APzE[23] undergoes inefficient but measurable photoisomerization. However, as the solvent polarity increases, $\Phi_{t \to c}$ for *t*-2-AQE and *t*-4-AQE increases while still virtually zero for *t*-3-AQE. The quantum yields of *trans* → *cis* photoisomerization of *t*-2-AQE and *t*-4-AQE are slightly increased with the solvent polarity and then decreased in polar protic sol-

Table 1. Absorption maxima (λ_a^{max}), fluorescence maxima (λ_f^{max}), quantum yields (Φ_f), and photoisomerization quantum yields ($\Phi_{t \to c}$) of *t*-2-AQE in various solvents at room temperature.

solvent	$E_T(30)^a$	λ_a^{max}, nm(ϵ^{max})	λ_f^{max}, nm	Φ_f	$\Phi_{t \to c}$
hexane	30.9	394(14,500)	483	0.41	<0.01
toluene	33.9	397(10,200)	499	0.29	-
THF	37.4	399(14,300)	498	0.18	0.09
EtOAc	38.1	395(13,300)	497	0.13	0.12
CH2Cl2	41.1	400(13,200)	502	0.08	0.15
CH3CN	46.0	391(15,000)	502	0.04	0.15
EtOH	51.9	397(15,400)	505	0.03	0.10
MeOH	55.5	394(14,700)	518	0.02	0.09

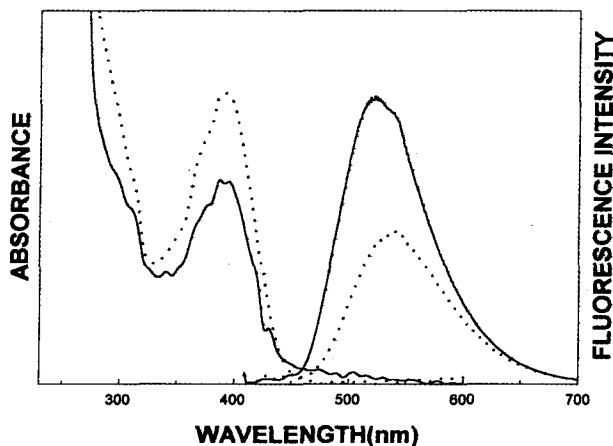[a] Dimroth's empirical solvent polarity parameter

Figure 2. Absorption (left) and fluorescence (right) spectra of *t*-3-AQE in hexane (solid line) and methanol (dotted line) at room temperature.
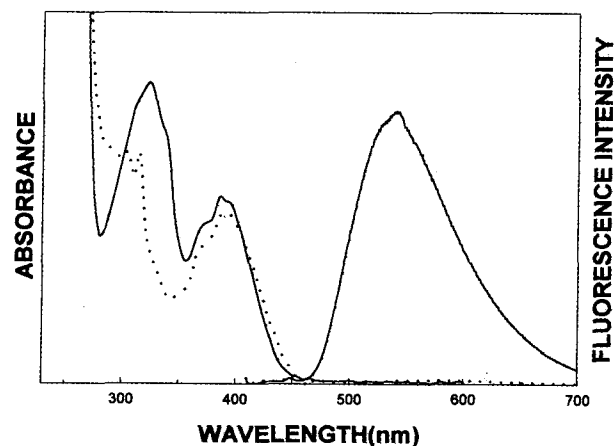

Figure 3. Absorption (left) and fluorescence (right) spectra of *t*-4-AQE in hexane (solid line) and methanol (dotted line) at room temperature.

Table 2. Absorption maxima (λ_a^{max}), fluorescence maxima (λ_f^{max}), quantum yields (Φ_f), and photoisomerization quantum yields ($\Phi_{t \to c}$) of t-3-AQE in various solvents at room temperature.

solvent	$E_T(30)^a$	λ_a^{max}, nm(ϵ^{max})	λ_f^{max}, nm	Φ_f	$\Phi_{t \to c}$
hexane	30.9	391(8,000)	482	0.26	<0.01
toluene	33.9	392(9,400)	490	0.36	<0.01
THF	37.4	391(9,800)	492	0.37	<0.01
EtOAc	38.1	387(8,200)	488	0.43	<0.01
CH$_2$Cl$_2$	41.1	391(8,700)	500	0.46	<0.01
CH$_3$CN	46.0	391(8,100)	500	0.34	<0.01
EtOH	51.9	391(5,900)	500	0.69	<0.01
MeOH	55.5	391(8,200)	502	0.15	<0.01

Table 3. Absorption maxima (λ_a^{max}), fluorescence maxima (λ_f^{max}), quantum yields (Φ_f), and photoisomerization quantum yields ($\Phi_{t \to c}$) of t-4-AQE in various solvents at room temperature.

solvent	$E_T(30)$	λ_a^{max}, nm(ϵ^{max})	λ_f^{max}, nm	Φ_f	$\Phi_{t \to c}$
hexane	30.9	388(9,200)	500	0.19	0.07
toluene	33.9	391(9,300)	504	0.04	0.11
THF	37.4	392(8,700)	504	0.020	0.14
EtOAc	38.1	391(8,500)	505	0.017	0.18
CH$_2$Cl$_2$	41.1	392(9,000)	504	0.014	0.20
CH$_3$CN	46.0	388(8,800)	521	0.005	0.17
EtOH	51.9	391(6,500)	523	0.009	0.15
MeOH	55.5	392(8,500)	530	0.004	0.15

Figure 4. Plausible energy diagrams for photoisomerization of t-n-AQE.

vent (methanol, ethanol). For t-3-AQE(Table 2) which exhibits considerable Φ_f in solvents of various polarity, no photoisomerization is observed in all used solvent but some other reaction or decomposition occurs on prolonged irradiation. The quantum yields of $trans \to cis$ photoisomerization and Φ_f of t-2-AQE and t-4-AQE show, at least partly, inverse relationship in varing the solvent polarity(Tables 1 and 3). As solvent polarity increases, Φ_f greatly decreases and $\Phi_{t \to c}$ slightly increases. It is inferred that photoisomerization of t-2-AQE and t-4-AQE proceeds partly on the excited singlet surface as in parent 9-APE and its derivatives.[9-20] It is thought that polar solvent stabilizes charge transfer state compared with locally excited state and shifts equilibrium in excited trans isomer toward charge transfer state, and thus may lead to open the pathway of $trans \to cis$ photoisomerization. The excited state involved in $trans \to cis$ photoisomerization is presumed to be a polar intramolecular charge transfer state as in some 9-APE derivatives containing electron-donating and electron-accepting substituents to the para-position on the phenyl moiety.[16-20]

As the solvent polarity is increased, in our previous studies for t-n-APyE (n=2, 4)[22] and t-APzE,[23] the fluorescence quantum yield is decreased and photoisomerization quantum yield is complementarily increased due to the lowering of energy barrier against twisting in the excited state through the intramolecular charge-transfer. But, photoisomerization quantum yields of t-2-AQE and t-4-AQE are not noticeably
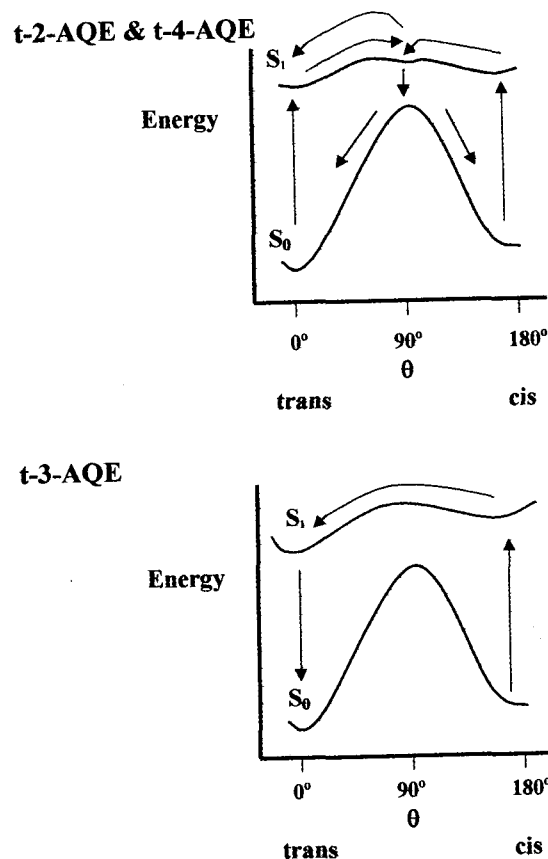
increased, while the fluorescence quantum yields are significantly decreased with the solvent polarity. This can be explained that nonradiative decay processes become efficient in polar solvent due to the presence of the polycyclic aza-aromatic ring.

Polycyclic aza-aromatics are generally known to exhibit fast radiationless decay attributed by efficient internal conversion and intersystem crossing. The fact that $\Phi_{t \to c}$ of t-n-AQE is lower than those of t-n-APyE (n=2 or 4) is probably due to more efficient nonreactive radiationless deactivation in t-n-AQE than in t-n-APyE (n=2 or 4).

T-3-AQE cannot undergo photoisomerization in all the solvent used. Photoisomerization of t-2-AQE cannot be observed in nonpolar solvent. However, photoisomerization of t-4-AQE accomplishes, even if inefficient. $\Phi_{t \to c}$ of t-4-AQE is higher in various solvents and more rapidly enhanced than t-2-AQE as solvent polarity increases. This reflects more polar character of t-4-AQE than to t-2-AQE. In polar solvent, $trans \to cis$ photoisomerization becomes feasible through intramolecular charge transfer, thereby Φ_f decreases. This trend is more pronounced for t-4-AQE. Plausible energy diagrams for photoisomerization of t-n-AQE are suggested in Figure 4.

REFERENCES

1. Saltiel, J., J. D'Agostino, E. D. Megarity, L. Metts, K. R. Neuberger, M. Wrighton and O. C. Zafirou (1973) The cis-trans Photoisomerization of Olefins. *Org. Photochem.* **3**, 1-113.

2. Saltiel, J. and J. L. Charlton (1980) cis-trans Isomerization of Olefins, In *Rearrangements in Ground and Excited States*, ed. by P. de Mayo. Academic Press, New York, Vol. 3, pp 25-89.

3. Waldeck, D. H. (1991) Photoisomerization Dynamics of Stilbenes. *Chem. Rev.* **91**, 415-436.

4. Mazzucato, U.(1982) Photophysical and Photochemical Behaviour of Stilbene-like Molecules and Their Aza-Analogues. *Pure Appl. Chem.* **54**, 1705-1721.

5. Meier, H. (1992) The Photochemistry of Stilbenoid Compounds and Their Role in Materials Technology. *Angew. Chem. Int. Ed. Engl.* **31(11)**, 1399-1540.

6. Arai, T., T. Karatsu, H. Misawa, Y. Kuriyama, H. Okamoto, T. Hiresaki, H. Furuuchi, H. D. Zeng, H. Sakaragi and K. Tokumaru (1988) Novel Insights into Photoisomerization of Olefins. *Pure Appl. Chem.* **60**, 989-998.

7. Arai, T. and K. Tokumaru (1993) Photochemical One-Way Adiabatic Isomerization of Aromatic. Olefins, *Chem. Rev.* **93**, 23-39.

8. Arai T. and K. Tokumaru (1995) Present Status of The Photoisomerization about Ethylenic Bonds. *Adv. Photochem.* **20**, 1-57.

9. Bhattacharyya, K., S. K. Chattopadhyay, S. Baral-Tosh and P. K. Das (1986) Excited-State Properties of trans-(9-Anthryl)ethylenes. Effects of Geometric Distortion about Single Bond. *J. Phys. Chem.* **90**, 2646-2651.

10. Bartocci, G., F. Masetti, U. Mazzucato, A. Spalletti, G. Orlandi and G. Poggi (1988) A Photophysical and Theoretical Study of Styrylanthracenes. *J. Chem. Soc. Faraday Trans. 2.* **84**, 385-399.

11. Bartocci, G., U. Mazzucato, A. Spalletti, G. Orlandi and G. Poggi (1992) Effect of the Nature of the Aromatic Groups on the Lowest Excited States of trans-1,2-Diarylethenes. *J. Chem. Soc. Faraday Trans.* **88**, 3139-3144.

12. Görner, H., F. Elisei and G. G. Aloisi (1992) Photoinduced Electron Transfer between Styrylanthracenes and Electron

Donors and Acceptors in Acetonitrile. *J. Chem. Soc. Faraday Trans.* **88**, 29-34.

13. Mazzucato, U, A. Spalletti and G. Bartocci (1993) Evidence of Adiabatic Channels in the Singlet Photoisomerization of cis-1,2-Diarylethenes: a Fluorimetric Study. *Coord. Chem. Rev.*, **125**, 251-260.

14. Aloisi, G. G., F. Elisei, L. Latterini, U. Mazzucato and M. A. J. Rodgers (1996) Excited State Behavior of Diarylethenes in the Subnanosecond Timescale: The Role of an Upper Singlet. *J. Am. Chem. Soc.* **118**, 10879-10887.

15. Bartocci, G., A. Spalletti and U. Mazzucato (1995) Solvent and Temperature Effects on the Fluorescence and Competitive Photoreactions of cis-9-Styrylanthracene. *Res. Chem. Intermed.* **21(7)**, 735-747.

16. Sandros, K. and H.-D. Becker (1987) Adiabatic Photochemical Isomerization of cis-1-(9-Anthryl)-2-phenylethenes. *J. Photochem.* **39**, 301-315.

17. Görner, H. (1988) cis-trans Photoisomerization of 1-(9-Anthryl)-2-phenylethylenes: Effects of Substitution and Solvent Polarity. *J. Photochem. Photobiol., A:Chem.* **43**, 263-289.

18. Sun, L. and H. Görner (1993) Excited-State Properties of trans-1-(9-Anthryl)-2-(4-R-phenyl)ethylenes with Electron-Donating and Accepting Substituents (R=N(CH$_3$)$_2$, OCH$_3$, CH$_3$, Br, CN, and NO$_2$). *J. Phys. Chem.* **97**, 11186-11193.

19. Sun, L and H. Görner (1993) Trans—cis Photoisomerization of 1-(9-Anthryl)-2-(4-R-phenyl)ethylene, R: CH3 and OCH$_3$. *Chem. Phys. Lett.* **208**, 43-47.

20. Aloisi, G. G., F. Elisei, L. Latterini, M. Passerini and G. Galiazzo (1996) (E)-9-Styrylanthracene Derivatives and Their Interactions with Electron Donors and Acceptors. *J. Chem. Soc. Faraday Trans.* **92**, 3315-3320.

21. Shin, E. J, S. H. Kim and H. K. Kang (1994) cis-trans Photoisomerization of 4-(2-(9-Anthryl)vinyl)pyridine; An Aza Analogue of 1-(9-Anthryl)-2-phenylethene. *J. Photoscience,* **1(2)**, 113-117.

22. Shin, E. J., E. Y. Bae, S. H. Kim, H. K. Kang, S. C. Shim (1997) Photophysical Properties and Photoisomerization Behaviour of 1-(9-Anthryl)-2-(n-pyridyl)ethenes (n=2, 3, or 4) pyridine; Aza Analogues of 1-(9-Anthryl)-2-phenylethene. *J. Photochem. Photobiol. A: Chem.* **107**, 137-146.

23. Shin, E. J. and S. W. Choi (1998) Photoisomerization Behaviour of 1-(9-Anthryl)-2-(2-pyrazinyl)ethene, A diaza Analogue of 1-(9-Anthryl)-2-phenylethene. *J. Photochem. Photobiol. A: Chem.* **114**, 23-30.

24. Shin, E. J. (1999) Photophysical Properties and Photoisomerization Behaviour of 1-(9-Anthryl)-2-(2-quinolinyl)ethene. *Bull. Korean. Chem. Soc.* **20**, 1263-1268.