Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Dyes and Pigments 75 (2007) 413–419
DYES and PIGMENTS
www.elsevier.com/locate/dyepig

Synthesis, characterization and spectroscopic investigation of azo-porphyrins

Xin-Gang Liu, Ya-Qing Feng*, Yao Zhao, Hong-Liang Chen, Xiang-Gao Li

School of Chemical Engineering and Technology, Tianjin University, Tianjin 300072, China

Received 26 July 2005; received in revised form 18 December 2005; accepted 12 June 2006
Available online 18 September 2006

Abstract

A series of novel covalently connected azonaphthalene porphyrin derivatives were prepared by linking azonaphthalene groups through a diazo-coupling reaction. They were characterized by UV–vis, IR, ^{1}H NMR and ESI-MS spectroscopic techniques. Azo–hydrazone tautomerism was studied using ^{1}H NMR and UV–vis techniques. The two chromophores of these derivatives exhibited their absorption spectroscopic properties and the effect of solvent upon the absorption ability was examined. In the fluorescence emission spectra, intermolecular fluorescence quenching was detected.

Keywords: Porphyrin; Azonaphthalene; Diazo-coupling reaction; Keto–hydrazo form; UV–vis spectra; Fluorescence quenching

1. Introduction

Porphyrins and their derivatives have become the current focus of research due to their outstanding physico-chemical properties and applications in diverse fields. Well-designed porphyrin derivatives can act as models for natural photosynthetic system [1–4], and as molecular switches [5–7] and other organic photoelectric materials [8–10]. In these fields the investigation of photoinduced electron transfer is essential in understanding the mechanism and processes of these molecular scale electronic components.

Azo compounds are very important in the fields of dyes, pigments and advanced materials [11]. They can perform *cis–trans* isomerization under photochemical reactions and might undergo energy transfer [12,13]. Moreover, the azo–hydrazone tautomerism in disperse azo dyes [14–18] is one of the interesting research fields because it is very important for their optical stability and usage. It is explained by the proton transfer between the O and imine N atoms, which also has potential use as the basis of optical data storage devices [19,20].

Recently, the compounds containing two chromophores, azo and porphyrin, including the azobenzene-linked porphyrins [21,22] and diporphyrins bridged by azo linkage [23–26], have been synthesized to develop new materials for molecular devices. But in these reported azo-porphyrin conjugates the azonaphthalene porphyrins did not involved. So the synthesis and their properties of the covalently linked two-component porphyrin system need further theoretical and experimental studies.

In the field of our investigation, we are interested in the development of a new class of azo-porphyrin chromophores. And very recently, we described the preparation and spectroscopic properties of the new azo-porphyrins that were synthesized using amino-porphyrins with phenol and naphthol [27]. As a continuation of our previous work in this area, we report herein the synthesis of the new azo-porphyrins **2** and **3**, in which the azonaphthalene groups are in the *para* position of the tetraphenylporphyrin and they are di-(**a**), tri-(**b**) and tetra-(**c**) substituted. The photochemical behaviors of the new compounds were examined using UV–vis absorption and fluorescence spectra. Since azo groups and porphyrins

---

* Corresponding author. Tel./fax: +86 22 27401824.
E-mail address: yqfeng@tju.edu.cn (Y.-Q. Feng).

0143-7208/$ - see front matter © 2006 Published by Elsevier Ltd.
doi:10.1016/j.dyepig.2006.06.021

absorb light in different regions of the UV–vis spectrum, the two moieties should address independently. Moreover, new compounds **2** and **3** should confer molecular recognition properties on the system having hydrogen-bonding sites.

2. Experimental

2.1. General

All solvents and compounds were analytical grade reagents and were purified before use by distillation. Silica gel (100–200 mesh) was used for column chromatography. Melting points are uncorrected. ^{1}H NMR spectra were recorded in $CDCl_3$ using TMS as an internal standard on a Bruker AC-P300 at 300 MHz. Absorption spectra were obtained with Helios γ instrument. The IR spectra were recorded with a BIO-RAD FTS3000 FT-IR spectrometer. The mass spectra (MS) were recorded with a Finnigan LCQ mass spectrometer (ESI). The fluorescence spectra were obtained using Fluoro-Max-P spectrometer.

2.2. Synthesis

Amido-porphyrins (**1**) were synthesized as described by a previously reported method [28].

2.2.1. Synthesis of azo-porphyrins (**2**)

Porphyrins **1a–c** (1 mmol) were suspended in concentrated hydrochloric acid (1.6 mL) and distilled water (10 mL) in an ice bath. Cold sodium nitrite (0.21 g, 3 mmol) was added portion-wise and the reaction mixture was further stirred for 25 min at 0–5 °C. Residual HNO_2 was destroyed by adding carbamide and the reaction mixture was further stirred for 15 min to give a solution. The resultant diazonium solution after filtering was used in the coupling reaction. A mixture of the coupling component phenol or β-naphthol and 10% sodium carbonate was stirred as to get a clear solution. The diazonium mixture was added at −5 to 0 °C and the solution was stirred for 40 min before raising the pH to 8–9 with aqueous sodium carbonate. The resulting precipitate was filtered off and washed with a minimal amount of water. The crude product was chromatographed through a silica gel column (100–200 mesh) using petroleum ether, dichloromethane and ethyl acetate as the eluent. A violet band and purple crystalline solid porphyrins **2a–c** were obtained.

*2.2.1.1. 5,15-Bis(4-nitrophenyl)-10,20-bis(4-(2-hydroxy-azonaphthyl)-phenyl) porphyrin (**2a**).* $R_f = 0.51$ (petroleum ether/dichloromethane/ethyl acetate = 3:30:1, v/v/v); purple solid; 0.84 g, yield: 80%; mp > 300 °C. ^{1}H NMR ($CDCl_3$, 300 MHz) δ: −2.73 (s, 2H, NH), 6.94 (d, $J = 9.9$ Hz, 2H, H*), 7.46 (m, 2H, ArH), 7.62–7.65(m, 4H, ArH), 7.79–7.82 (m, 2H, ArH), 8.15–8.18 (m, 4H, ArH), 8.33–8.44 (m, 8H, ArH), 8.62–8.70 (m, 6H, ArH), 8.80 (d, $J = 3.9$ Hz, 4H, pyrrole-H), 9.01 (d, $J = 3.3$ Hz, 4H, pyrrole-H), 16.60 (s, 2H, OH); IR (KBr) ν/cm^{-1}: 3410, 3059, 2959, 2925, 2854, 1726, 1629, 1599, 1512, 1467, 1385, 1283, 1209, 1137, 1075, 963, 846, 799, 746; ESI-MS *m/z* found: 1045.7, calcd for $C_{64}H_{40}N_{10}O_6$: 1045.3 $(M + H)^+$.

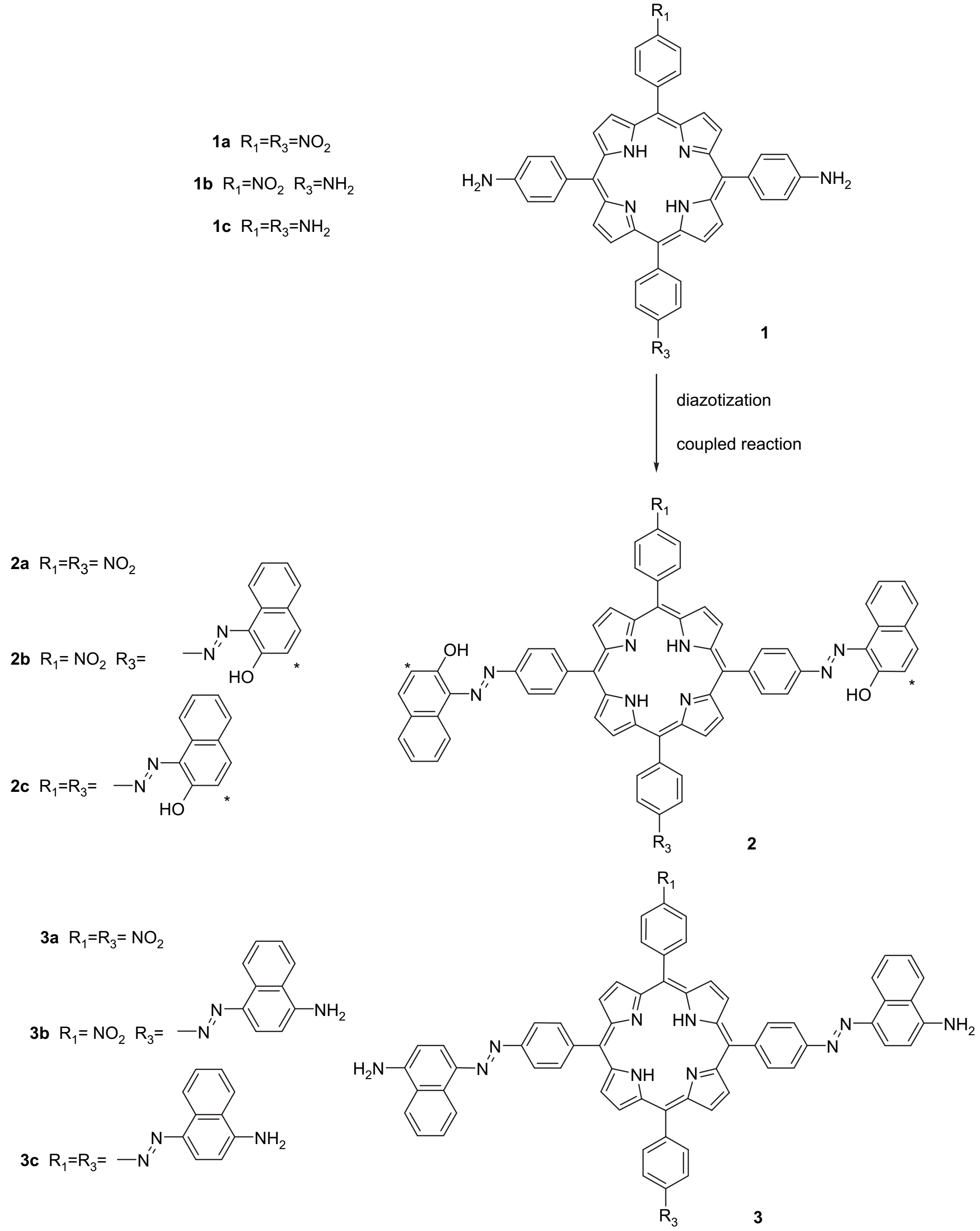
*2.2.1.2. 5-(4-Nitrophenyl)-10,15,20-tris(4-(2-hydroxy-azonaphthyl)-phenyl) porphyrin (**2b**).* $R_f = 0.22$ (petroleum ether/dichloromethane/ethyl acetate = 3:30:1, v/v/v); purple solid; 0.92 g, yield: 79%; mp > 300 °C. ^{1}H NMR ($CDCl_3$, 300 MHz) δ: −2.69 (s, 2H, NH), 6.94 (d, $J = 9.3$ Hz, 3H, H*), 7.45–7.48 (m, 3H, ArH), 7.60–7.67 (m, 6H, ArH), 7.79–7.82 (m, 3H, ArH), 8.15–8.18 (m, 6H, ArH), 8.34–8.45 (m, 8H, ArH), 8.66–8.73 (m, 5H, ArH), 8.80–8.81 (m, 2H, pyrrole-H), 9.00 (s, 6H, pyrrole-H), 16.60 (s, 3H, OH); IR (KBr) ν/cm^{-1}: 3438, 3319, 2956, 2926, 2857, 1721, 1620, 1596, 1504, 1451, 1399, 1345, 1254, 1207, 1148, 965, 840, 798, 750; ESI-MS *m/z* found: 1171.8, calcd for $C_{74}H_{47}N_{11}O_5$: 1171.4 $(M + 2H)^+$.

*2.2.1.3. 5,10,15, 20-Tetra(4-(2-hydroxy-azonaphthyl)-phenyl) porphyrin (**2c**).* $R_f = 0.10$ (petroleum ether/dichloromethane/ethyl acetate = 3:30:1, v/v/v); purple solid; 1.06 g, yield: 82%; mp > 300 °C. ^{1}H NMR ($CDCl_3$, 300 MHz) δ: −2.69 (s, 2H, NH), 6.94 (d, $J = 9.6$ Hz, 4H, H*), 7.45–7.48 (m, 4H, ArH), 7.60–7.67 (m, 8H, ArH), 7.79–7.82 (m, 4H, ArH), 8.15–8.18 (m, 8H, ArH), 8.34–8.45 (m, 8H, ArH), 8.66–8.73 (m, 4H, ArH), 8.99 (s, 8H, pyrrole-H), 16.60 (s, 4H, OH); IR (KBr) ν/cm^{-1}: 3426, 3316, 3075, 2925, 2854, 1720, 1620, 1599, 1556, 1502, 1453, 1400, 1346, 1256, 1149, 985, 966, 799, 753; ESI-MS *m/z* found: 1296.0, calcd for $C_{84}H_{54}N_{12}O_4$: 1296.4 $(M + 2H)^+$.

2.2.2. Synthesis of azo-porphyrins (**3**)

Porphyrins **1a–c** (1 mmol) were suspended in concentrated hydrochloric acid (1.6 ml) and distilled water (10 ml) in an ice bath. Cold sodium nitrite (0.21 g, 3 mmol) was added portion-wise and the reaction mixture was further stirred for 25 min at 0–5 °C. Residual HNO_2 was destroyed by adding carbamide and the reaction mixture was further stirred for 15 min to give a solution. The resultant diazonium solution after filtering was used in the coupling reaction. A mixture of the coupling component α-naphthylamine and 10% sodium acetate was stirred as to get a clear solution. The diazonium mixture was added at −5 to 0 °C and the solution was stirred for 40 min before dilution or raising the pH to 6–7 with aqueous sodium acetate. The resulting precipitate was filtered off and washed with a minimal amount of water. The crude product was chromatographed through a silica gel column (100–200 mesh) using petroleum ether, dichloromethane and ethyl acetate as the eluent. A violet band and purple crystalline solid porphyrins **3a–c** were obtained.

*2.2.2.1. 5,15-Bis(4-nitrophenyl)-10,20-bis(4-(4-amino-azonaphthyl)-phenyl) porphyrin (**3a**).* $R_f = 0.46$ (petroleum ether/dichloromethane/ethyl acetate = 3:30:1, v/v/v); purple solid; 0.77 g, yield: 74%; mp > 300 °C. ^{1}H NMR ($CDCl_3$, 300 MHz) δ: −2.73 (s, 2H, NH), 4.73 (s, 4H, NH_2), 6.92–8.46 (m, 26H, ArH), 8.66 (d, $J = 8.1$ Hz, 2H, pyrrole-H), 8.80 (d, $J = 4.5$ Hz, 2H, pyrrole-H), 9.02 (s, 4H, pyrrole-H), 9.23



Scheme 1. Azo-porphyrin derivatives.

(d, 2H, $J = 8.4$ Hz, ArH); IR (KBr) ν/cm^{-1}: 3477, 3380, 3330, 2956, 2923, 2852, 1718, 1618, 1577, 1514, 1463, 1398, 1334, 1261, 1190, 1138, 964, 798; ESI-MS *m/z* found: 1043.7, calcd for $C_{64}H_{42}N_{12}O_4$: 1043.3 $(M + H)^+$.

*2.2.2.2. 5-(4-Nitrophenyl)-10,15,20-tris(4-(4-amino-azonaphthyl)-phenyl) porphyrin (**3b**).* $R_f = 0.28$ (petroleum ether/dichloromethane/ethyl acetate = 3:30:1, v/v/v); purple solid; 0.84 g, yield: 72%; mp > 300 °C. ^{1}H NMR (CDCl$_3$, 300 MHz) δ: −2.67 (s, 2H, NH), 4.71 (s, 6H, NH$_2$), 6.92–8.46 (m, 32H, ArH), 8.66 (d, $J = 8.7$ Hz, 1H, pyrrole-H), 8.80 (d, $J = 5.1$ Hz, 1H, pyrrole-H), 9.03 (s, 6H, pyrrole-H), 9.23 (d, 2H, $J = 8.7$ Hz, ArH); IR (KBr) ν/cm^{-1}: 3456, 3392, 2954, 2922, 2850, 1618, 1572, 1514, 1460, 1398, 1332, 1259, 1223, 1192, 1138, 964, 796, 756; ESI-MS: *m/z* found 1167.7, calcd for $C_{74}H_{50}N_{14}O_2$, 1167.4 $(M + H)^+$.

*2.2.2.3. 5,10,15, 20-Tetra(4-(4-amino-azonaphthyl)-phenyl) porphyrin (**3c**).* $R_f = 0.12$ (petroleum ether/dichloromethane/ethyl acetate = 3:30:1, v/v/v); purple solid; 0.93 g, yield: 72%; mp > 300 °C. ^{1}H NMR (CDCl$_3$, 300 MHz) δ: −2.62 (s, 2H, NH), 4.71(s, 8H, NH$_2$), 6.92–8.42 (m, 34H, ArH), 9.02

(s, 8H, pyrrole-H), 9.24 (d, 2H, $J = 8.1$ Hz, ArH); IR (KBr) ν/cm^{-1}: 3483, 3398, 2920, 2850, 1624, 1572, 1518, 1466, 1400, 1332, 1261, 1192, 1140, 966, 798, 758; ESI-MS *m*/*z* found: 1291.8, calcd for $C_{84}H_{58}N_{16}$: 1291.5 $(M+H)^+$.

3. Results and discussion

3.1. Synthesis and characterizations

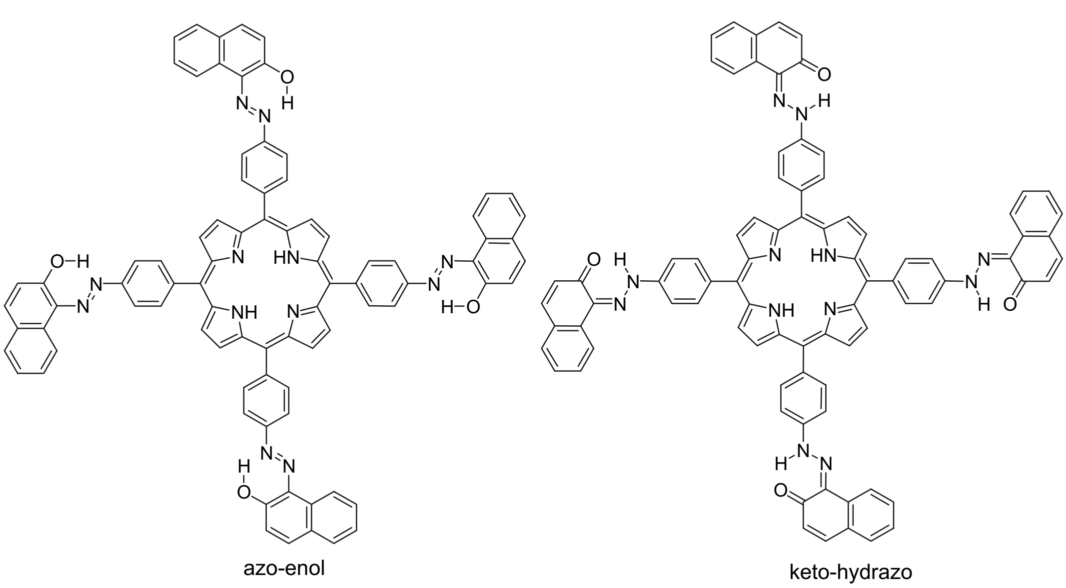
The bi-(**a**), tri-(**b**) and tetra-(**c**) substituted azo-porphyrin conjugates **2a–c** and **3a–c** were prepared by diazotization of amino-porphyrins **1a–c** using concentrated hydrochloric acid at room temperature, and coupling with naphthol and naphthylamine (Scheme 1). The starting compounds **1a–c** were easily synthesized by deoxidization from tetranitrophenylporphyrin [27].

All reactions proceeded smoothly producing the corresponding azo compounds in good yields. The azo-porphyrin dyes were characterized by FT-IR, ^{1}H NMR, ESI-MS and UV–vis spectroscopic techniques.

The IR spectra of chromophores (**2a–c** and **3a–c**) showed a weak band within the range 3483–3395 cm^{-1} corresponding to ν_{OH} (compounds **2**) and ν_{NH} (compounds **3**). The low value revealed that the –OH and –NH groups were involved in intramolecular H-bonding. The IR spectra also showed a weak bond or shoulder located at 2983–2854 cm^{-1} which was assigned to aromatic C–H, stretching vibration of the N=N group leading to the band located in the 1467–1452 cm^{-1} region. It can be suggested from broad –OH bands at 3440–3395 cm^{-1} in the infrared spectra that compounds **2** may exist as the azo–enol form in the solid state.

From the ^{1}H NMR spectra in the $CDCl_3$, the NH protons of the porphyrins **2a–c** and **3a–c** appeared as one singlet around δ −2.7. Also, the ^{1}H NMR spectra of compounds **2a–c** and **3a–c** showed single or double bands at about δ 9.0 corresponding to β-pyrrolic protons. But due to the presence of nitro-group, four and two β-pyrrolic protons shifted to around δ 8.8 in compounds **2a** and **2b**, respectively, while the β-pyrrolic protons shifted to around δ 8.6 and 8.8 in compounds **3a** and **3b**, respectively. Furthermore, the pyrrolic protons showed doublets in compounds **2a** and **3a**. This indicated that compounds **2a** and **3a** should be *trans* but not *cis* substituted. This was identical with Vicente's results [29]. The OH protons of compounds **2** appeared as one singlet at δ 16.6 in the ^{1}H NMR spectra, while NH_2 of compounds **3** appeared at δ 4.7. In addition, H* proton in compounds **2** shifted to high fields (around δ 6.9) and the coupling constant was up to $J = 9.3$–9.9. These findings suggest that compounds **2** exist as the keto–hydrazo form in $CDCl_3$ (Scheme 2) according to literature results [30,31].

UV–vis absorption spectra were measured using a Helios γ spectrophotometer in the wavelength range 200–800 nm. The absorption spectra of porphyrins showed the typical Soret and Q-bands at the concentration of about 5×10^{-6} mol/L. From the UV–vis absorption spectra (Fig. 1) the porphyrinic Soret bands are broader compared with that of TPP (*meso*-tetraphenylporphyrin), indicating a ground state interaction of the azonaphthalene groups and porphyrin chromophore. Moreover, the Soret bands had strong tailings on the red edge of the absorption bands in compounds **3**. This may result from n → π* absorption of the *Z*-azonaphthalene moiety. This was identical with Hombrecher's results [24]. The absorption bands of compounds **2** and **3** show relatively weak and broadened bands in the azo groups' π → π* region at 309–356 nm. And the azo groups' bands of compounds **2** were markedly blue-shifted compared with those of compounds **3**. The Q-bands of new compounds **2** and **3** showed insignificantly affected; however, the azonaphthalene group



Scheme 2. The tautomeric forms of compound **2c**.

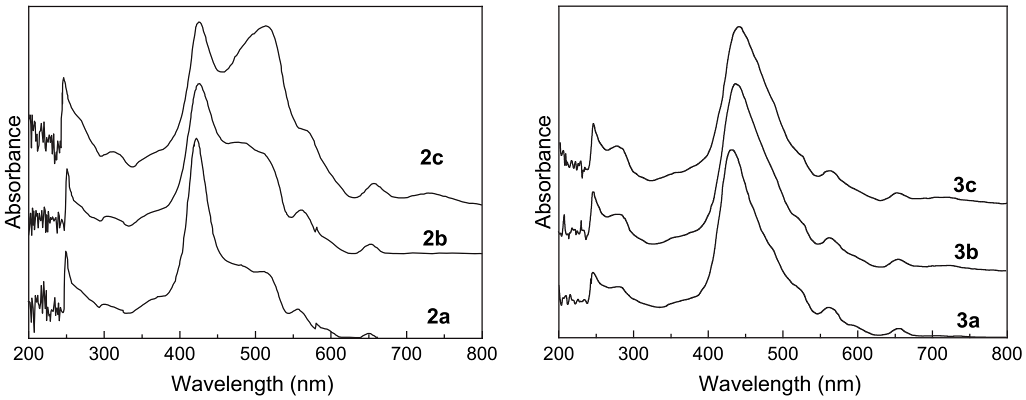


Fig. 1. UV–vis spectra of compounds **2** and **3** in chloroform (5×10^{-6} mol/L).

peaks near 510 nm of compounds **2** cover-up a Q-band of porphyrin moiety near 517 nm. It is clear furthermore that these peaks of **2** follow an increasing trend in height according to the increase of azonaphthalene group in **a**, **b** and **c**. Such findings also indicated that compounds **2** may exist as the keto–hydrazo form in chloroform [32].

As demonstrated in Fig. 2 the fluorescence peak intensity of **2** decreases significantly in the order of di-(**a**), tri-(**b**) and tetra-(**c**) azo-group substituted compounds. The porphyrin fluorescence of **2b** and **2c** are quenched by 7% and 45%, respectively, as compared to compound **2a**. And it is clear that the emission near 720 nm reduces markedly. These results evidently indicate that substantial amount of electron transfer occurs from the azonaphthalene group to the porphyrin chromophore in the excited state. In addition, compounds **2** have more emission peaks at 851 nm compared with TPP when excited at the azophenyl group with absorption maximum at 356 nm. In contrast, the fluorescence peak intensity increases with the addition of the azonaphthalene substituent. However, the fluorescence peaks of compounds **3** are not significantly quenched except the peak around 610 nm. Thus covalent connection of the chromophores **3** does not greatly perturb the excited state properties of the porphyrin component.

3.2. Solvent effect

The absorption spectra of azo dyes **2a–c** and **3a–c** were recorded in various solvents as a concentration of about 5×10^{-6} mol/L; the results are summarized in Table 1. And Fig. 3 shows the absorption spectra of compound **3b** in various solvents. The visible absorption spectra of compounds **2** and **3** were found to show that the typical Soret and Q-bands of porphyrin bands and azo bands did not significantly change except those in acetic acid. As is apparent in Fig. 3, the Soret band red-shifted to around 566 nm and the broad Q-band at 772 nm were observed.

4. Conclusions

In conclusion, the diazo-coupling reactions are shown in Scheme 1. This pathway is the most convenient to give the best yield of diazo-coupling porphyrin compounds. Six new bi-, tri- and tetra-substituted azonaphthalene-porphyrin conjugates with hydrogen-bonding groups immersed had been synthesized. The characterization of these new compounds had been described and the ^{1}H NMR and absorption spectra results of dyes **2** revealed that these compounds do exist in forming azo–enol form and keto–hydrazo form species.

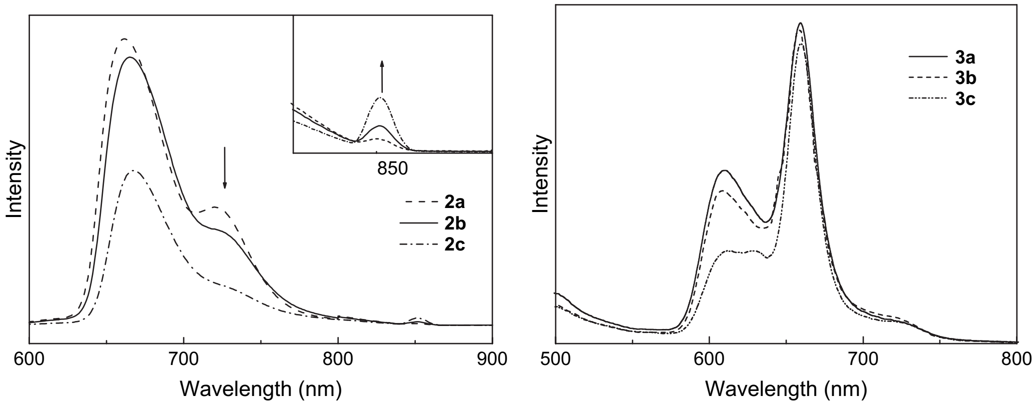


Fig. 2. The fluorescence spectra of porphyrins **2** and **3** in chloroform (5×10^{-6} mol/L).

Table 1
Influence of solvent on λ_{max} (nm) of dyes **2a–c** and **3a–c**

No.	Chloroform			Ethyl acetate			Acetonitrile			DMF			Acetic acid		
	λ_{azo}	λ_{Soret}	λ_Q	λ_{azo}	λ_{Soret}	λ_Q	λ_{azo}	λ_{Soret}	λ_Q	λ_{azo}	λ_{Soret}	λ_Q	λ_{azo}	λ_{Soret}	λ_Q
2a	303 512	424	502 559 580 653	321 511	415	550 647	326 515	414	580 651	311 512	425	559 591 652	318 536	440	695
2b	305 511	426	489 559 580 653	321 512	419	554 653	330 512	420	580 650	312 508	427	561 594 652	316 534	441	705
2c	309 514	426	513 566 656 725	323 511	423	551 650	321 512	422	580 650	309 508	426	565 654	316 515	438	705
3a	356	432	520 564 592 652	352	425	558 598 652	353	417	553 593 650	356	424	500 561 653	365	450 567	776
3b	356	436	523 562 652	353	441	561 599 654	351	420	555 593 651	356	424	501 561 653	366	561	772
3c	354	440	520 562 658	352	449	560 601 654	357	448	561 589 652	353	421	500 563 654	366	533	773

The electronic spectra of new compounds exhibited the typical bands of azo, Soret and Q, and the intramolecular electronic communications between azonaphthalene and porphyrin units were detected. However, they did not significantly change along with the various solvents. Owing to fluorescence quenching, chromophores **2** showed intramolecular electron transfer. Thus, they are potentially capable of molecular sensing or switching applications. More detailed studies of the photochemistry of these compounds are presently under investigation.

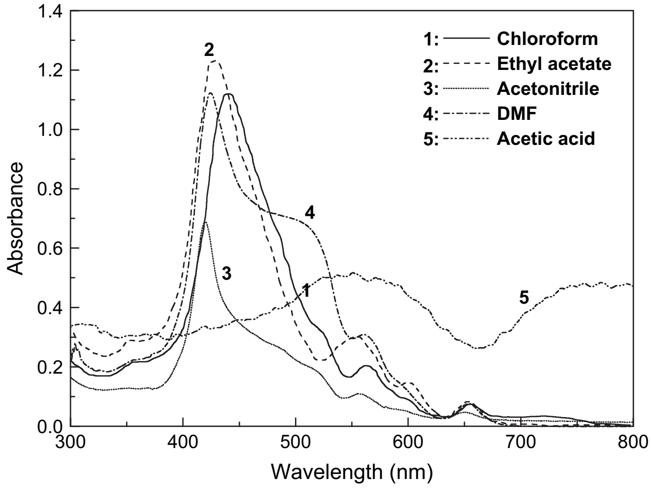


Fig. 3. Absorption spectra of dye **3b** in various solvents.

Acknowledgements

This work was supported by the National Natural Science Foundation (No. 20376059) and the National High Technology Research and Development Program of China (863 Program) (No. 2002AA325050).

References

[1] Harriman A, Sauvage JP. Chem Soc Rev 1996;25:41–8.

[2] Wagner RW, Johnson TE, Lindsey JS. J Am Chem Soc 1996;118:11166–80.

[3] Seth J, Palaniappan V, Johnson TE, Prathapan S, Lindsey JS, Bocian DF. J Am Chem Soc 1994;116:10578–92.

[4] Nakano A, Osuka A, Yamazaki I, Yamazaki T, Nishimura Y. Angew Chem Int Ed Engl 1998;37:3023–7.

[5] Michael PO, Mark P, Niemczyk WA, Svec D, Gosztola GL, Gaines MW. Science 1992;257:63–5.

[6] Lucia F, Giancarlo M, Isabelle MD, Jean-Paul C, Jean-Pierre S. J Phys Chem B 2002;106:6663–71.

[7] Liddell PA, Kodis G, Moore AL, Moore TA, Gust D. J Am Chem Soc 2002;124:7668–9.

[8] Wasielewski MR. Chem Rev 1992;92:435–61.

[9] Gosztola D, Niemczyk MP, Wasielewski MR. J Am Chem Soc 1998;120:5118–9.

[10] Lidzey DG, Bradley DDC, Skolnick MS, Virgili T, Walker S, Whittaker DM. Nature 1998;395:53–5.

[11] Waring DR, Hallas G. The chemistry and application of dyes. New York: Plenum; 1990.

[12] Kumar GS, Neckers DC. Chem Rev 1989;89:1915–25.

[13] Murakami H, Kawabuchi A, Kotoo K, Kunitake M, Nakashima N. J Am Chem Soc 1997;119:7605–6.

[14] Cheon KS, Park YS, Kazmaier PM, Buncel E. Dyes Pigments 2002;53:3–14.

[15] Hihara T, Okada Y, Morita Z. Dyes Pigments 2003;59:25–41.

[16] Nedeltcheva D, Damyanova B, Popov S. J Mol Struct 2005;749:36–44.

[17] Khedr AM, Gaber M, Issa RM, Erten H. Dyes Pigments 2005;67:117–26.

[18] Panea I, Pelea M, Silberg IA. Dyes Pigments 2006;68:165–76.

[19] Joshi H, Kamounah FS, Gooijer C, van der Zwan G, Antonov L. J Photochem Photobiol A Chem 2002;152:183–91.

[20] Park H, Choi W. J Photochem Photobiol A Chem 2003;159:241–7.

[21] Autret M, Le Plouzennec M, Moinet C, Simonneaux G. J Chem Soc Chem Commun 1994;1169–70.

[22] Hunter CA, Sarson LD. Tetrahedron Lett 1996;37:699–702.

[23] Neumann KH, Vögtle F. J Chem Soc Chem Commun 1988;520–2.

[24] Hombrecher HK, Lüdtke K. Tetrahedron 1993;49:9489–94.

[25] Shinji T. J Am Chem Soc 1999;121:48–53.

[26] Yamamura T, Momotake A, Arai T. Tetrahedron Lett 2004;45:9219–23.

[27] Liu XG, Feng YQ, Li F, Chen X, Li XG, Zhang CY. Chin Chem Lett 2005;16:1181–4.

[28] Zhu BK, Xu ZK, Xu YY. Chin J Appl Chem 1999;16:68–70.

[29] Luguya R, Jaquinod L, Frnczek FR, Vicente MGH, Smith KM. Tetrahedron 2004;60:2757–63.

[30] Tian YZ, Wu ZW, Zhang SF, Wang GJ. J Chem Ind Eng (China) 1995;46(2):152–7.

[31] Peng Q, Li M, Gao K, Cheng L. Dyes Pigments 1990;14:89–99.

[32] Dakiky M, Kanan K, Khamis M. Dyes Pigments 1999;41:199–209.