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SHORT COMMUNICATION

Synthesis of Novel Spiro-Oxazino-Quinoline Derivatives and Study of Their Photophysical Properties

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Abstract A convenient route was successfully developed for the synthesis of novel heterocycles such as spiro-oxazino-quinoline derivatives from 2-aminoquinoline-3-carbonitrile (4) in good yield. The Spiro-quinoline derivatives (6, 8 and 10) were synthesized and further studied for their photophysical properties. Semiempirical molecular orbital calculation (PM3/PM6 for structure) proves to be a suitable tool for the prediction of absorption and fluorescence properties of these compounds.

Keywords Spiro-oxazino-quinoline · Absorption and emission · Quantum yields · Heat of formation · HOMO-LUMO

Introduction

Organic luminophores, as basic dopants for polymer matrixes, are known to be used in construction of electroluminescent light emitting diodes (LEDs), electroluminescent (ELDs), thin film transistor and photovoltaic devices. The spectral range of the fluorescence may be modified by switching to pyrazolo-quinoline (PQ) derivatives, i.e. by introducing a different type of organic or inorganic substituents. The absorption and emission spectra in this case significantly depend on the substitution pattern as well as on the type of substituents [1, 2]. A prominent example is diethyl amine pyrazolo-quinoline-derivative which generates a sharp *green* electro-luminescence [3]. Further improvement/modification of basic characteristics of organic luminophores requires a detailed knowledge concerning their electronic properties. Important information on this account may be obtained by studying an *optical absorption* and photoluminescence in UV/Vis parts of the spectra in combination with a *quantum chemical modeling*. H. Ze and co-workers reported the synthesis of pyrazolo[3,4-*b*]quinoline derivatives with the efficient blue photoluminescence and energy transfer in polymer materials [4]. Thus a suitable blue-emitting material with high brightness and good thermal stability still remains to be developed.

In our earlier publications [5–8] we have reported the synthesis of dipyrazolo[3,4-*b*:3,4-*d*]pyridines (DPP), pyrazolo[3,4-*b*]pyrrolo[2,3-*d*]pyridines (PPP) and pyridine-3-carbonitriles which showed remarkable fluorescent properties. We noted that the fluorescent properties of these derivatives depend upon the nature of substituents on the phenyl ring in dipyrazolo[3,4-*b*:3,4-*d*]pyridine (DPP) and on the phenyl group attached to N-atom of pyrazole ring in pyrazolo[3,4-*b*] pyrrolo[2,3-*d*]pyridines (PPP). Encouraged by this study and hunt for new fluorescent compounds, we investigated the novel synthesis and photophysical properties of spiro-oxazino-quinolines.

Result and discussion

The synthesis of spiro-quinolone derivatives **6**, **8** and **10** were achieved from highly reactive starting material, 2-aminoquinoline-3-carbonitrile **4** and cyclic ketone **5**, **7** and **9**. Compound **4** has been synthesized starting with 2-aminobenzaldehyde [9, 10]. The compound **1** containing bifunctional groups (NO_2 and CHO) was used as precursor

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for the synthesis of 2-aminoquinoline-3-carbonitrile **4**. Thus, commercially available compound **1** on reaction with malanonitrile in ethanol containing catalytic amount of piperidine at 20–25 °C furnished an open chain compound **2** in 80% yield. After successful reduction of nitro to amino by using reducing agent $Fe/FeCl_3$ gave compound **4** (without isolation of **3**) in 80% yield (Scheme 1). Compound **4** is an important intermediate for the various heterocyclic compounds and we have used it for the synthesis of spiro-compounds **6**, **8** and **10**. Thus, the compound **4** on reaction with cyclic ketones **5**, **7** and **9** in presence of Lewis acid ($ZnCl_2$) yielded spiro-quinoline derivatives in 60–70% yield (Scheme 2). The structure of compound **6**, **8** and **10** were confirmed by spectroscopic analysis. For example, the ^1H NMR spectrum of spiro compound **6a** showed triplet at δ 1.3 for two protons of methylenes group. The multiplet between δ 2.80–2.90 due to eight protons of 4-CH_2 group of cyclohexane moiety in **6a**. The multiplet between 7.22–7.80 corresponded to four protons of benzene ring in **6a**. Singlet appeared at δ 8.50 for aromatic proton of pyridine ring. Both the NH and C=NH protons showed broad singlet at δ 8.40 and 10.20 respectively. The mass spectrum of **6a** displayed a molecular ion peak *m/z* at 267, which is constituent with the molecular weight of **6a**. The structure of the other compounds **8** and **10** were established on the basis of spectroscopic and analytical data (experimental section).

Mechanism

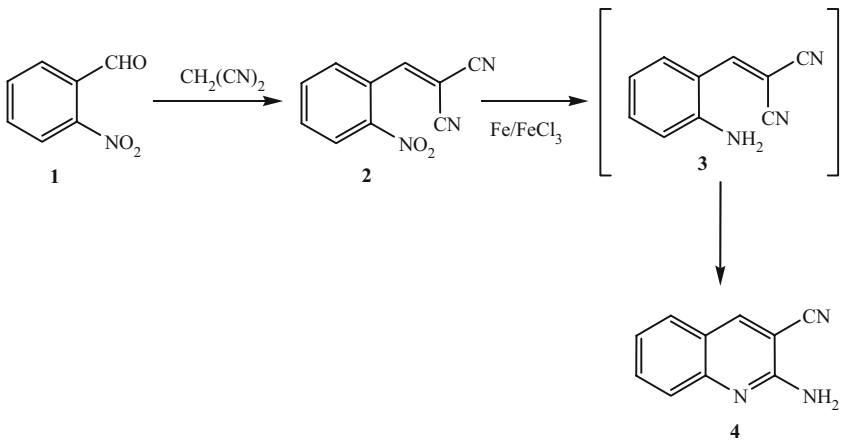
The proposed mechanism for the formation of spiro[1, 3] oxazino[4,5-b]quinoline-2,1′-cyclohexan-4(1H)-imine (**6**, **8**, **10**) derivatives can be explained by Scheme 3. The nucleophilic attack of the amino group of **4** onto the carbonyl carbon atom of cyclic ketone gave intermediate **11** and the product (**6**, **8** and **10**) were obtained through subsequent cyclization by attack of the oxygen atom onto the nitrile group of **4**.

Photophysical properties

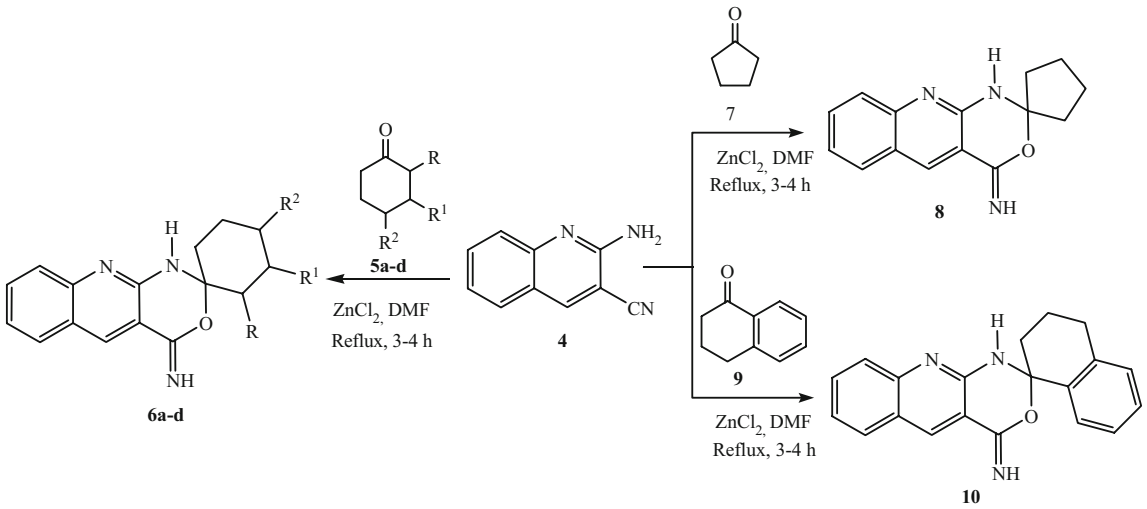
The photophysical properties of compounds **6**, **8** and **10** were determined with respect to quinine sulphate which was used as a reference standard for the present study. Compounds **6**, **8** and **10** showed (Table 1) absorption and emission in near visible region and it is remarkable that compound **6b** showed absorption in visible region (UV λ_{Max}=430 nm) and emission (Em λ_{Max}=480.5 nm). It was noted that, when compound **4** was condensed with 4-methylcyclohexanone (**5b**), the resulted spiro-quinoline compound **6b** showed red-shifted absorption as compared to **6a**, **6c** and **6d** (Fig. 1). This may be due to the presence of electron donating methyl group at *para* position in **6b**. These finding reveals that the compound **6b** exhibit remarkable fluorescent character with high quantum yield (ϕ_F=0.21) in comparison with other derivatives of **6a**, **6c**, **6d**, **8** and **10**.

Semi-empirical study

The gain interest into the atomic contribution on the frontier orbital, we analyzed the three-dimensional HOMO and LUMO coefficient contribution by the MOPAC-2009 (Version 8.331) [11, 12] and are given in Table 2. From this we observed that, 2-aminoquinoline-3-carobonitrile (**4**) has low GAP values (eV=7.792) hence it is more thermally stable than **6**, **8** and **10**. This indicated higher overlapping of HOMO or LUMO orbital in the molecules **4** (Table 2).



Scheme 1 Synthetic route for 2-aminoquinoline-3-carbonitrile



6a) R, R^1, R^2 = H, **6b**) R, R^1 = H, R^2 = CH_3, **6c**) R = CH_3, R^1, R^2 = H, **6d**) R, R^2 = H, R^1 = CH_3

Scheme 2 Synthetic route for spiro-oxazino-quinolines (**6**, **8** and **10**)

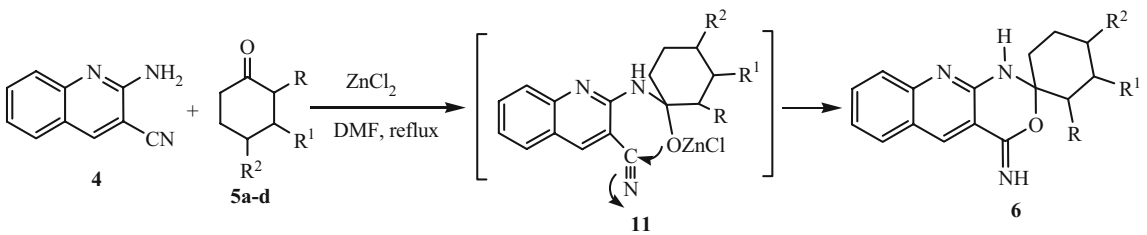
Conclusion

In conclusion, we have described a novel and efficient method for the synthesis of spiro-oxazino-quinoline derivatives via cyclocondensation of substituted 2-aminoquinoline-3-carobonitrile **4** and cyclic ketones (**5**, **7** and **9**) using easily available Lewis acid catalyst $ZnCl_2$. Compounds **6**, **8** and **10** showed very good fluorescent properties and it was noted spiro-compound (**6b**) obtained by the condensation of 4-methylcyclohexanone with compound **4**, absorb in visible region ($\lambda_{Max.}$=430 nm). Thermal analysis of compounds **6a**–**d**, **8** and **10** by differential scanning calorimetry (DSC) showed that they are thermally stable up to 300 °C. The efficient blue light emission and physical and chemical stability makes spiro-oxazino-quinoline a promising family of materials which may be useful in opto-electronic applications. The practical results obtained are in agreement with the HOMO, LUMO and heat of formation obtained by the semiempirical PM3/PM6 methods.

Experimental

General

Melting points were determined on a *Barnstead Electro Thermal* melting point apparatus, Mod. No. IA-9200 in open capillary tubes. The ^{1}H NMR (300 MHz) and ^{13}C NMR (75 MHz) spectra were recorded on Varian *XL*-300 spectrometer. Chemical shifts were reported in ppm from internal tetramethylsilane standard and are given δ-units. The solvent for NMR spectra was deutero-chloroform unless otherwise stated. Infrared spectra were taken on Shimadzu IR-408, instrument in potassium bromide pellets unless otherwise stated. Elemental analyses were performed on a Hosli CH-Analyzer and are within ±0.3 of the theoretical percentage. High-resolution mass spectra were obtained with a Mat 112 Varian Mat Bremen (70 *eV*) mass spectrometer. Column chromatography was carried out on silica gel (s.d. Fine Chemicals, 60–80 mesh). Solutions were concentrated in a rotary evaporator under reduced



Scheme 3 Proposed mechanism

Table 1 The photophysical data for electronic (UV $\lambda_{Max.}$) and fluorescence (Em $\lambda_{Max.}$) and quantum yield (ϕ) of compounds **4**, **6**, **8** and **10** in $CHCl_3$ as the solvents at 25 °C

Compound	UV λ_{Max}/nm	Em λ_{Max}/nm	Φ
4	364.0	422.0	0.17
6a	379.5	445.5	0.19
6b	430.0	480.5	0.21
6c	387.5	439.5	0.19
6d	389.5	448.5	0.20
8	383.5	434.4	0.18
10	386.5	465.0	0.19

pressure. All reactions were monitored by thin layer chromatography (TLC), carried out on 0.2 mm silica gel 60 F_{254} (Merck) plates using UV light (254 and 366 nm) for detection. Common reagents-grade chemicals are either commercially available 2-aminobenzaldehyde [10] and were used without further purification or prepared by standard literature procedures. Semiempirical molecular orbital calculations were done by semiempirical PM3/PM6 methods, MOPAC [11, 12] program package.

Procedure for the synthesis of 2-(2-nitrobenzylidene)-malononitrile (2)

A mixture of compound **1** (5 g, 0.033 mol) and malononitrile (2.4 g, 0.036 mol) was dissolved in ethanol (25 mL) and stirred at room temperature for 5 h. After completion (TLC Check Toluene: Acetone 8:2), reaction mixture was poured in ice-cold water (100 mL), and further stirred for 1 h to obtained colorless solid. Filtered, dried and recrystallized from ethanol to afford colorless prism in 80% yield, mp 141–143 °C, IR (KBr): 2985 m, 2715 s, 2225 m, 1540 m, 1480 m, 1623 s, 922 s, 752 m cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 7.21 (s, 1H, CH), 7.96–8.43 (m, 4H, ArH), MS (70 eV) *m/z* (%): 199(20) [M +1], 168(60), 150(60), 118(100), 102(90). Anal. calcd. For $C_{10}H_5N_3O_2$ (199.17): C, 60.35; H, 2.53; N, 21.11. Found: C, 60.48, H, 2.73, N, 21.23.

Procedure for the synthesis of 2-aminoquinoline-3-carbonitrile (4)

A mixture of compound **2** (10 g, 0.05 mol) and Fe (Iron) powder (12.75 g, 0.25 mol) was added in 100 ml ethanol and mixture was stirred at 40–45 °C for 30 min. Then solution of $FeCl_3$ (0.63 g, $FeCl_3$ dissolved in 6 ml water) was added drop wise in above reaction mixture. After complete addition, reaction mixture was refluxed for 7–8 h (TLC Check), filtered, and half of the solvent was evaporated under vacuum and remaining reaction mixture was quenched in ice-cold water (100 mL), to obtain the yellow color solid. Filtered, dried and recrystallized from THF to afford yellow crystal of **4**. Yield: 7.2 g (80%); mp 188–192 °C, IR(KBr): 3396 m, 3321 m, 3161 m, 2225 s, 1652 s, 920 m, 748w, cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 5.45 (bs, 2H, NH_2), 8.30 (s, 1H, ArH), 7.24–7.66 (m, 4H, ArH). MS (70 eV) *m/z* (%): 170 (50) [M+1], 155 (100), 113 (80), 108(60). Anal. Calcd. For $C_{10}H_7N_3$ (169.18): C, 71.07; H, 4.17; N, 24.84. Found: C, 71.28, H, 4.28, N, 24.92.

General procedure for the synthesis of spiro[1, 3]oxazino [4,5-b]quinoline-(6, 8 and 10)

To a solution of DMF (10 mL) and $ZnCl_2$ (1.6 g, 0.0118 mol) were added substituted 2-aminocarbonitrile **4** (2 g, 0.0118 mol) and cyclic ketone (4 mL) (**5a**–**d**, **7**, **9**). The mixture was heated at reflux for 3–4 h. After completion of the reaction as indicated by the TLC (eluent: ethyl acetate: n-hexane 9:1), the cooled reaction mixture was quenched with water (15 mL) and the precipitate was separated by filtration. The filtration residue was dispersed into water and titrated to pH 12–13 by 30% sodium hydroxide. After filtration the crude product was purified by recrystalistaion.

Spiro[1,3]oxazino[4,5-b]quinoline-2, 1'-cyclohexan]-4(1H)-imine (6a)

Yield: 2.05 g (65%), recrystallized from ethylacetate to afford yellow solid; mp 236–238 °C. IR (KBr): 3254 m, 3175 m, 2856 m, 1654 s, 1618 s, 1562 m, 1436 m, 804 m, 761 m cm^{-1}. ^{1}H NMR (300 MHz, DMSO-d_6) δ :1.31 (t, 2H, CH_2), 2.80–2.90 (m, 8H, 4×CH_2), 7.22–7.80 (m, 4H, ArH), 8.40 (bs, 1H, NH), 8.50 (s, 1H, ArH), 10.20(bs, 1H, NH). MS (70 eV) *m/z* (%): 268 (40, [M+1], 265(70), 249(80), 237(10), 169

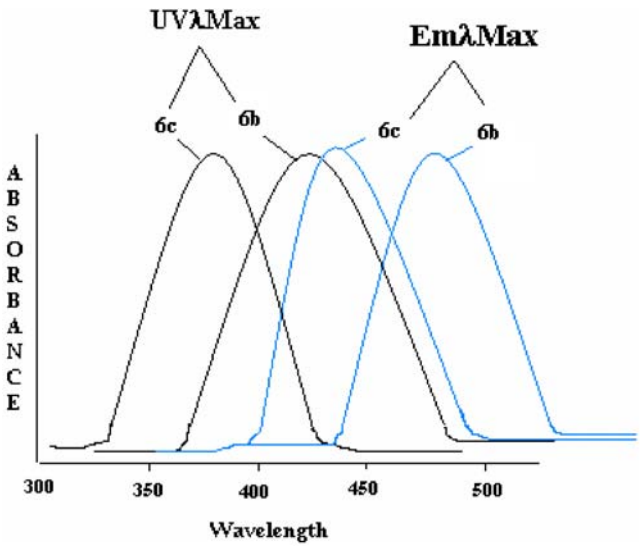


Fig. 1 The comparative absorption (UV $\lambda_{Max.}$) and emission (Em $\lambda_{Max.}$) spectra of compounds (**6b**) and (**6c**) respectively

Table 2 The molecular electronic properties (HOMO-LUMO energy, GAP) of the spiro-oxazino-quinolines (**6**, **8** and **10**) and 2-aminoquinoline-3-carobonitrile (**4**)

Comp.	R	R^1	R^2	Heat of formation (K Cal.)	Ionization potential (eV)	HOMO (eV)	LUMO (eV)	GAP (eV)
4	–			79.30	9.015	−9.015	−1.223	7.792
6a	H	H	H	5.53	8.80	−8.80	−0.903	7.897
6b	H	H	CH_3	0.132	8.80	−8.80	−0.904	7.896
6c	CH_3	H	H	1.69	8.72	−8.725	−0.881	7.844
6d	H	CH_3	H	1.017	8.79	−8.793	−0.889	7.904
8	–	–	–	10.43	8.83	−8.834	−0.937	7.897
10	–	–	–	39.38	8.79	−8.794	−0.979	7.815

GAP = E_{LUMO}-E_{HOMO}

(20), 142(10), 127(30), 113(15). Anal. Calcd. For $C_{16}H_{17}N_3O$ (267.33): C, 71.97; H, 6.41; N, 15.73. Found C, 72.19; H, 6.63; N, 15.51.

4-Methylspiro[1,3]oxazino[4,5-b]quinoline-2, 1'-cyclohexan]-4(1H)-imine (6b)

Yield: 2.15 g (65%), recrystallized from ethyl acetate to afford pale yellow crystal; mp 242–244 °C. IR (KBr): 3248 m, 3168 m, 2949 m, 2927 m, 1672 s, 1622 s, 1577 m, 1390 m, 806 m, 766 m cm^{-1}. ^1H NMR (300 MHz,$CDCl_3$) δ: 0.91 (d, 3H, CH_3), 1.30 (q, 2H, CH_2), 1.60 (q, 1H, CH), 1.80 (t, 4H, 2×CH_2), 2.20(t, 2H, CH_2), 3.80 (bs, 1H, NH), 6.90 (bs, 1H, NH), 7.20–7.60 (m, 4H, ArH), 8.60 (s, 1H, ArH). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 22, 38, 68, 112, 124, 126, 130, 132, 136, 140, 148, 154, 162. Anal. Calcd. For $C_{17}H_{19}N_3O$ (281.35): C, 72.66; H, 6.81; N, 14.95. Found C, 72.43; H, 6.52; N, 14.71.

2-Methylspiro[1,3]oxazino[4,5-b]quinoline-2, 1'-cyclohexan]-4(1H)-imine(6c)

Yield: 2.20 g (68%), recrystallized from ethanol to afford pale yellow crystal; mp 235–238 °C. IR (KBr): 3186 m, 3051 m, 2929 m, 1666 s, 1620 s, 1578 m, 1502 s, 1433 s cm^{-1}. ^1H NMR (300 MHz, DMSO-d_6) δ: 0.9 (d, 3H, CH_3), 1.22 (q, 1H, CH), 1.50 (t, 2H, CH_2), 1.60 (t, 2H, CH_2), 1.72 (t, 2H, CH_2), 1.94 (t, 2H, CH_2), 8.35 (bs, 1H, NH), 8.40 (bs, 1H, NH), 7.20–7.80 (m, 4H, ArH), 8.60 (s, 1H, ArH). MS (70 eV) *m/z* (%): 282 (50) [M+1], 265(10), 241 (40), 169 (20), 127(10). Anal. Clacd. For $C_{17}H_{19}N_3O$ (281.35): C, 72.66; H, 6.81; N, 14.95. Found C, 72.44; H, 6.78; N, 14.68.

3-Methylspiro[1,3]oxazino[4,5-b]quinoline-2, 1'-cyclohexan]-4(1H)-imine(6d)

Yield: 1.90 g (60%), recrystallized from ethanol to afford yellow crystal; mp 228–230 °C. IR (KBr): 3170 m, 3077 m, 2950 m, 1680 s, 1620 s, 1560 m, 1489 m, 818 m, 768 m cm^{-1} ^1H NMR (300 MHz, DMSO-d_6) δ: 0.82 (d, 3H, CH_3), 1.20 (t, 2H, CH_2), 1.55–1.90 (t, 7H, 3×CH_2 and CH), 7.70 (bs, 1H, NH), 8.50 (bs, 1H, NH), 7.20 (t, 1H, ArH), 7.5–7.6 (dd, 2H, ArH), 7.90 (d, 1H, ArH), 8.60 (s, 1H, ArH). Anal. Calcd. For $C_{17}H_{19}N_3O$ (281.35): C, 72.66; H, 6.81; N, 14.95. Found C, 72.52; H, 6.58; N, 14.68.

Spiro[1,3]oxazino[4,5-b]quinoline-2,1'-cyclopentan]-4 (1H)-imine (8)

Yield: 1.79 g (60%), recrystallized from ethanol to afford yellow crystal; mp 236–238 °C IR (KBr): 3174 m, 3057 m, 2939 m, 1685 s, 1618 s, 1568 m, 1502 m, 1429 m, 810 m, 760 m cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ: 1.85 (q, 4H, 2×CH_2), 2.01 (q, 4H, 2×CH_2), 5.80 (bs, 1H, NH), 6.70 (bs, 1H, NH), 7.20–7.80 (m, 4H, ArH), 8.60(s, 1H, ArH). MS (70 eV) *m/z* (%): 253 (90) [M+1], 241(50), 236(90), 202 (40), 169(20), 127(20). Anal. Calcd. For $C_{15}H_{15}N_3O$ (253.3): C, 71.21; H, 5.97; N, 16.60. Found C, 71.41; H, 6.18; N, 16.88.

3',4'-Dihydro-2'H-spiro[1,3]oxazino[4,5-b]quinoline-2, 1'-naphthalen]-4(1H)-imine (10)

Yield: 2.60 g (70%), recrystallized from ethanol to afford pale yellow crystal; mp 266–268 °C. IR (KBr): 3178 m, 3024 m, 2935 m, 1654 s, 1618 s, 1573 m, 1504 m, 1433 m, 1390 m, 1346 m, 818 m, 755 m cm^{-1}. ^1H NMR (300 MHz, DMSO) δ: 2.04 (t, 2H, CH_2), 2.60 (t, 2H, CH_2), 2.80 (t, 2H, CH_2), 7.10–7.30 (m, 4H, ArH), 7.40–7.80 (m, 4H, ArH), 8.20 (bs, 1H, NH), 8.60 (s, 1H, ArH), 8.80 (bs, 1H, NH). ^{13}C NMR (75 MHz, DMSO) δ: 18, 28, 68, 111, 122, 123, 125, 126, 127, 128, 129, 131, 136, 139, 149, 154, 160. Anal. Calcd. For $C_{20}H_{17}N_3O$ (315.37): C, 76.26; H, 5.43; N, 13.33. Found C, 75.92; H, 5.21; N, 13.20.

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