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Unusual reactivity of 1-aminoanthraquinone in copper catalyzed multicomponent reaction with isatins and aryl alkynes: synthesis and photophysical properties of regioisomeric fluorescent 3-spiroheterocyclic 2-oxindoles

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ABSTRACT

Unusual reactivity of 1-aminoanthraquinone with a number of isatins and aryl alkynes in a copper catalyzed multicomponent reaction afforded a novel, highly conjugated, and separable regioisomers of 3-spiroheterocyclic 2-oxindoles in excellent combined yield. Both the regioisomers exhibited considerable optical properties and found as fluorescence materials. Based on experimental observation, a plausible reaction mechanism has been proposed.

1. Introduction

Multicomponent reactions[1,2] (MCRs) are regarded as powerful method for the rapid construction of complex molecular architectures in a one-pot and economical mode. Particularly, this diversity oriented[3] MCRs have been found broad application in the discovery of pharmaceutical lead structures. However, for the synthesis of materials with π-conjugated systems, such as electrophores, chromophores, and fluorophores have been used in the development of novel electronics,[4] photonics,[5] and biophysical analysis,[6] this approach is quite novel.[7,8] Transition metal catalyzed[9] MCRs for the synthesis of quinolines and indoles have paved the way to diverse classes of heterocycles.[10] Significantly, 3-spiroheterocyclic 2-oxindole cores have been found in a number of natural products, such as alstonisine,[11] tabernoxidine,[12] and medicinally important NITD 609[13] (Fig. 1). In addition to the significant biological activities of 3-spiroheterocyclic 2-oxindoles,[14] these compounds have emerged as potential fluorescent materials.[15] With this point of view, recently we have reported[16] the synthesis of highly luminescent acyclic merocyanine dye analogue materials via a multicomponent reaction using binary copper as a catalyst.[17]

Generally, coupling of an aldehyde, alkyne, and amine catalyzed by Cu(I) salts is known as A^3 coupling[18] and its ketone analogue is KA^2 coupling[19] and have been successfully utilized for the synthesis of propargylamine derivatives. In continuation of our research work in the synthesis of various 3-spirocyclic 2-oxindoles[20] from Morita–Baylis–Hillman (MBH) adduct of isatin and to overcome the

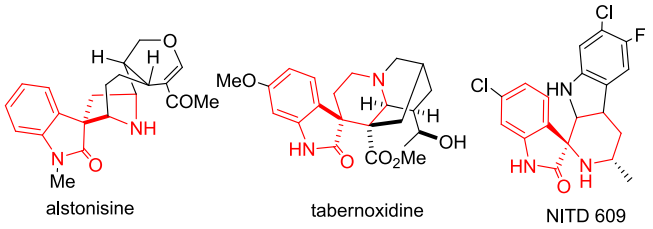

Fig. 1. Natural products and anti-malarial drug with 3-spiro-oxindole core structures.

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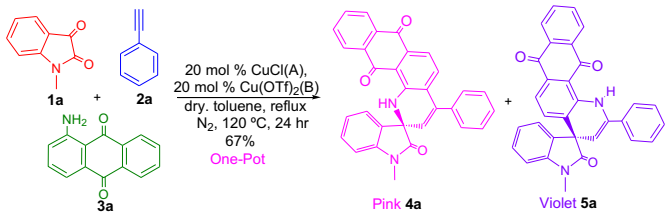
limited synthesis of chromophoric 3-spiroheterocyclic 2-indolones, a novel and efficient synthetic method has been developed by KA^2 type coupling of 1-aminoanthraquinone, 1-methylisatin, and aryl alkynes using copper as a catalyst (Scheme 1) and the details are presented in this manuscript. Notably, unlike the role of amines in A^3 or KA^2 coupling reactions, 1-aminoanthraquinone demonstrated an unusual reactivity to afford regioisomeric title compounds. This method has an advantage, such as readily available substrates, mild reaction condition, and simple column separation of regioisomers.



Scheme 1. Synthesis of regioisomeric 3-spiroheterocyclic 2-oxindoles **4a** and **5a**.

2. Results and discussion

Initially, to a mixture of 1-methylisatin **1a** (1 equiv), phenylacetylene **2a** (1 equiv), and 1-aminoanthraquinone **3a** (1.2 equiv) in dry toluene, 20 mol % each of CuCl (A) and Cu(OTf)$_2$ (B) catalysts was added under nitrogen atmosphere and the reaction mixture was stirred at 120 °C for 16 h (Scheme 1). In contradiction of previous report,[16] the reaction with 1-aminoanthraquinone as amine counterpart afforded regioisomeric 3-spiroheterocyclic 2-oxidoles **4a** and **5a** in 32% and 35% yield, respectively (Table 1, entry 1). The structure of compounds **4a** and **5a** were assigned by analysis of spectroscopic and analytical data (UV–vis, FT-IR, ^{1}H NMR, ^{13}C NMR, and HRMS) and unambiguously confirmed by a single crystal X-ray analysis (Fig. 2).[21]

Table 1
Optimization of synthesis of 3-spiroheterocyclic 2-oxindoles **4a** and **5a**

Entry	Ratio of **1a**:**2a**:**3a**	Mole ratio of catalyst (**A**:**B**)	Yield of **4a**:**5a** (%)
1	1:1:1.2	20:20	32:35
2	1:1.2:1	20:20	36:37
3	1:1.2:1.2	20:20	37:38
4	1:1.2:1.2	20:20	26:34[a]
5	1:1.2:1.2	05:05	16:35
6	**1:1.2:1.2**	**10:10**	**39:42**[c]
7	1:1.2:1.2	10:00	0
8	1:1.2:1.2	00:10	5:27
9	1:1.2:1.2	10:10	23:35[b]

[a] Performed on a preheated oil bath.
[b] Performed in air.
[c] Optimized condition.

It should be noted that the reactivity of 1-aminoanthraquinone in this reaction has been found completely altered and provided unusual and unique 3-spiroheterocyclic 2-oxindoles in a one-pot reaction. To optimize the synthesis of compounds **4a** and **5a**, a number of experiments with change in number of mole equivalent of reagents and catalysts have been carried out (Table 1). Change of the reactant mole ratio as 1:1.2:1.2 and 10 mol % of each CuCl/Cu(OTf)$_2$ catalysts under nitrogen atmosphere, provided compounds **4a** and **5a** in 81% combined yield and was found to be optimized condition (Table 1, entry 6). Increasing the mole equivalents of alkyne (1.5 equiv) and 1-aminoanthraquinone (1.5 equiv) lead to decrease in the yield. The presence of both CuCl and Cu(OTf)$_2$ catalysts is important since absence of one of the catalysts resulted lower yields of products (entries 7 and 8). It should be noted that gradual increase of the reaction temperature by

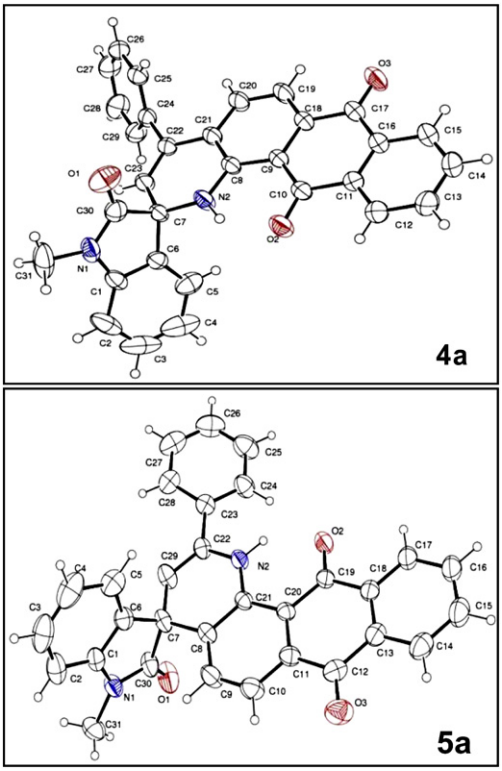


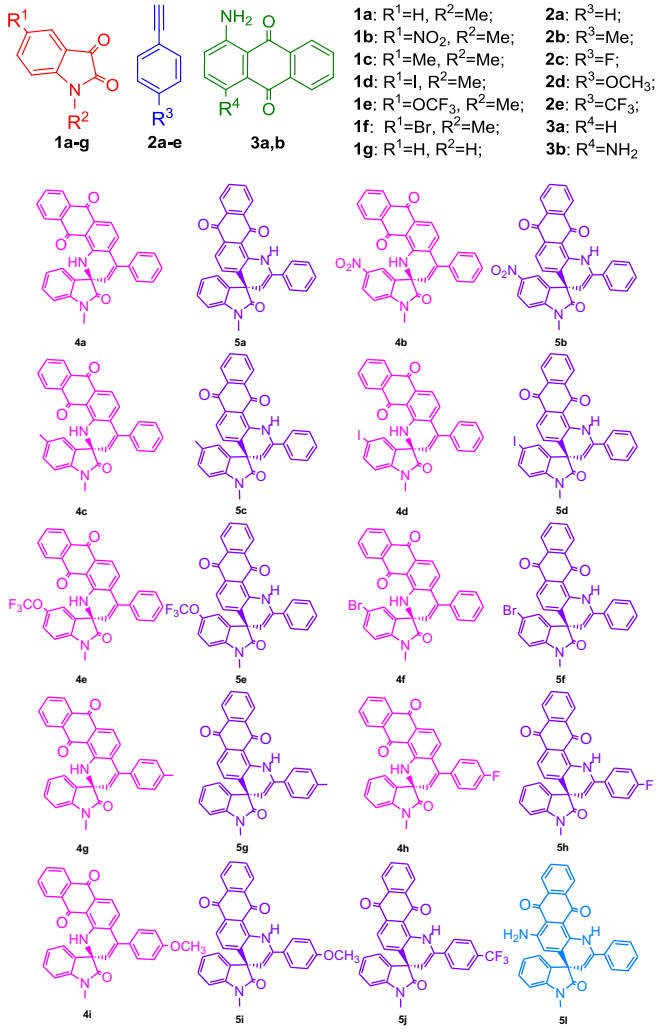
Fig. 2. ORTEP diagram of compounds **4a** and **5a**.[21]

3 °C/minute upto 120 °C resulted in a significantly higher yield than heating it on a preheated oil bath at 120 °C. Further, reactions at lower temperature (80 °C) and shortening time (16 h) also provided lower yields. However, all the cases, the ratio of the products was found to be relatively constant. Thus, offer information about two possible intermediates to propose a mechanism.

To demonstrate the scope and limitation of the reaction, under optimized condition, experiments with a number of substituted isatins **1a**–**g**, aryl alkynes **2a**–**e**, and 1-aminoanthraquinones **3a**,**b** have been carried out. All the reactions underwent smoothly and provided corresponding both regioisomeric spiro heterocycles **4a**–**i** and **5a**–**i** in excellent combined yield (Table 2). It has been observed that *N*-methylisatin with electron withdrawing group at fifth position of the aryl ring afforded better yield than those with electron releasing group. Isatin gave a trace amount of product **5k** along with inseparable mixture. 5-Nitroisatin and 5-methylisatin did not yield any product. Alkyne **2e** gave only product **5j**, presumably due to weak nucleophilicity. However, in contrary, the reaction with 2-aminoanthraquinone found to be failed and afforded inseparable complex mixture (Table 2, entry 12). The reaction with 1,4-diaminoanthraquinone **3b** gave only one product **5l**. To testify the reactions with other aryl amines, the reaction with 5-aminoquinoline gave only imine as a product. The reaction with 8-aminoquinoline and 5-amino-1,4-napthoquinone[22] gave inseparable mixture. The reaction with and 9-aminoacridine did not give any product and starting materials have been recovered.

Based on the isolated products **4a** and **5a**, a plausible mechanism is proposed as illustrated in Scheme 2. Thus, for compound **4a**, nucleophilic addition of Cu-phenyl acetylide to imine **A** obtained from isatin and 1-aminoanthraquinone to give propargylamine derivative **B**. Activation of alkyne in **B** by Cu(II) followed by an intramolecular Friedel–Crafts type cyclization to form cyclic intermediate **C**, which upon aromatization affords **4a**. For the other regioisomer **5a**, it is believed that initial Cu(I) catalyzed competitive nucleophilic addition of phenyl acetylide to isatin provide propargyl alcohol derivative

Table 2
Synthesis of spiroheterocyclic compounds **4a**–**i** and **5a**–**l**

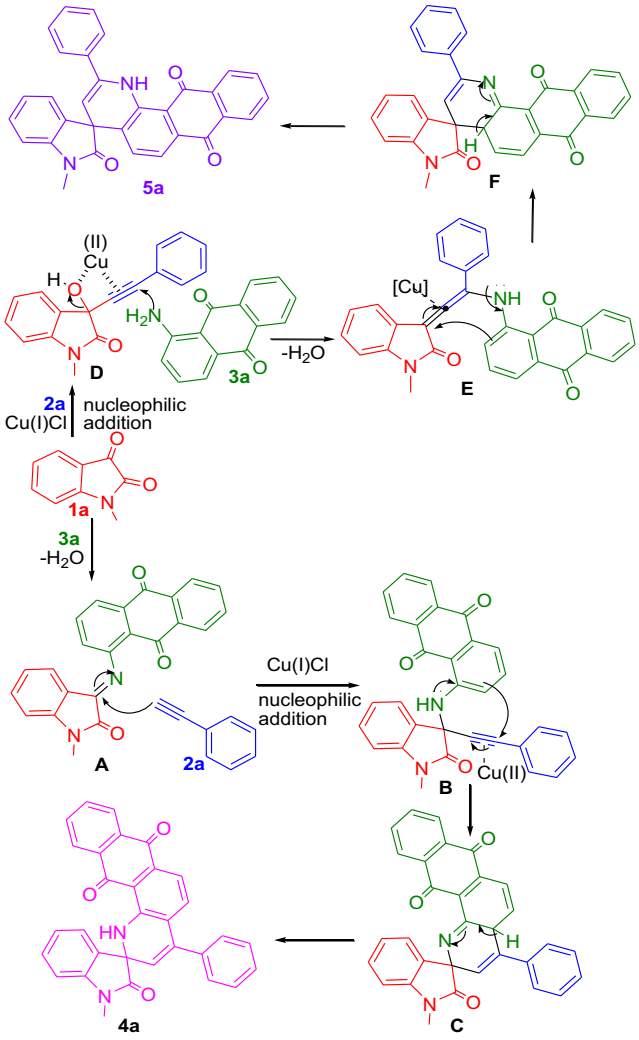


Entry	Isatin	Alkyne	Product(s)	Yield[a] (%)
1	**1a**	**2a**	**4a**(39)	**5a**(42)
2	**1b**	**2a**	**4b**(42)	**5b**(45)
3	**1c**	**2a**	**4c**(38)	**5c**(40)
4	**1d**	**2a**	**4d**(40)	**5d**(42)
5	**1e**	**2a**	**4e**(39)	**5e**(46)
6	**1f**	**2a**	**4f**(38)	**5f**(45)
7	**1a**	**2b**	**4g**(35)	**5g**(39)
8	**1a**	**2c**	**4h**(33)	**5h**(40)
9	**1a**	**2d**	**4i**(34)	**5i**(38)
10	**1a**	**2e**	—	**5j**(42)
11	**1g**	**2a**	—	**5k**(trace)
12[b]	**1a**	**2a**	—	—
13[c]	**1a**	**2a**	—	**5l**(46)

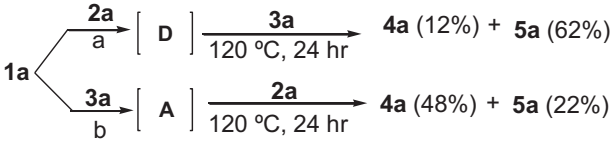
[a] All the reactions were carried out using isatins (1.00 mmol, 1.0 equiv), alkynes (1 mmol, 1.2 equiv), and amines (1 mmol, 1.2 equiv) with 10 mol % of each CuCl and $Cu(OTf)_2$ as catalysts.
[b] The reaction was carried out with 2-aminoanthraquinone.
[c] The reaction was carried out with 1,4-diaminoanthraquinone.

D. Simultaneous activation of alkyne and 3°-OH groups in **D** by Cu(II) followed by reaction with 1-aminoanthraquinone to afford allene intermediate **E**. Since copper coordination increases the electrophilicity of allene **E**, which then undergoes an intramolecular Friedel–Crafts type cyclization to intermediate **F**, which on aromatization affords **5a**.

To support the proposed mechanism, experiments with change of order of addition of reagents have been carried out (Scheme 3). In



Scheme 2. Plausible mechanism for the formation of **4a** and **5a**.



a. 10 mol % CuCl, 10 mol % $Cu(OTf)_2$, Toluene, N_2, 90 °C, 2.5 hr;
b. 10 mol % CuCl, 10 mol % $Cu(OTf)_2$, Toluene, N_2, 120 °C, 2.5hr

Scheme 3. Experimental support for the proposed mechanism.

the first experiment, *N*-methylisatin **1a** and phenylacetylene **2a** were stirred at 90 °C in the presence of binary Cu(I)/Cu(II) catalytic system for 2.5 h. Then 1-aminoanthraquinone **3a** was added and refluxed for 24 h at 120 °C afforded **4a** as a minor and **5a** as a major product. It revealed that major part of the reaction was proceeded through propargyl alcohol intermediate **D** (Scheme 2). In the other experiment, *N*-methylisatin **1a** and 1-aminoanthraquinone **3a** were refluxed at 120 °C in the presence of binary Cu(I)/Cu(II) catalytic system for 2.5 h. Then phenylacetylene **2a** was added and refluxed for 24 h at 120 °C results **4a** as a major and **5a** as a minor product. It revealed that major part of the reaction proceeded via imine intermediate **A**. However, in both the cases the combined yield is lesser than the original reaction carried out in a one-pot manner and both the isomers are formed but with altered product ratio.

Significantly, physical nature of compounds **4a** (pink) and **5a** (violet) prompted us to evaluate their photophysical properties.

Thus, both compounds **4a** and **5a** showed UV-absorption maxima in the visible region at 519 nm and 521 nm, respectively. Compound **4a** showed a 116 nm red shifted broad emission covering entire red region (620–730 nm) with a maxima at 635 nm, whereas compound **5a** showed dual emissive behavior of 30 nm red shifted orange-red emission with an emission maxima at 551 nm and a broad hump at 617 nm (Fig. 3). Further, the time correlated single photon counting measurement revealed the fluorescence lifetime decay of compound **4a** is bi-exponential with lifetimes of 0.396 ns (92.63%) and 6.47 ns (7.63%) while compound **5a** as tri-exponential with lifetimes of 0.751 ns (15.24%), 2.42 ns (37.67%) and 9.59 ns (47.09%) (Fig. 3). However, lower quantum yields of **4a** (0.02) and **5a** (0.006) have been measured using rhodamine 6G in ethanol as a reference. Further, change of excitation wavelength did not improve the quantum yield. The above data confirmed that compounds **4a** and **5a** are possible fluorescent spirocyclic 2-oxindole dye materials.

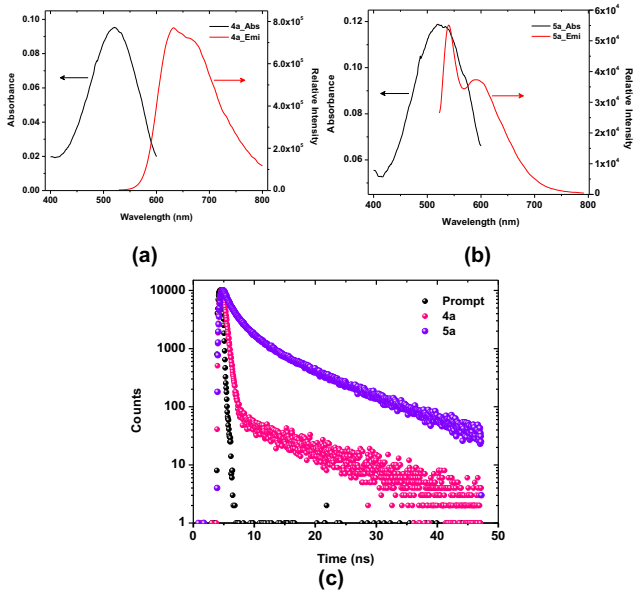


Fig. 3. Normalized absorption–emission spectra of **4a** (a), **5a** (b) and fluorescence lifetime of compounds **4a**/**5a** (c).

To understand the dual emissive behavior of **5a**, the fluorescence excitation spectra were recorded in acetonitrile. On monitoring at the shorter wavelength emission maximum (551 nm), two distinct excitation bands were observed, one at 460 nm and the other at 520 nm whereas for longer wavelength emission maximum (617 nm), it showed only one excitation band around 460 nm (Fig. 4(b)). The existence of two excitation band indicates that the origin of the dual emission behavior is from the two different chromophore of the same molecule.

The excitation band observed at 520 nm corresponds to the locally excited state and the one at 460 nm overlaps with the 1-aminoanthraquinone molecular absorption, which is shown in Fig. 5(a). Hence **5a** existing as a non conjugated but covalently linked bichromophoric system since the emission at 551 nm corresponds to the locally excited state whereas the emission at 617 nm may be due to the anthraquinone moiety. However such bichromophoric behavior is not observed in compound **4a** because of the extended π-conjugation provided by the phenylacetylene unit and hence the emission is solely due to the locally excited state (charge transfer from the spirocycle ring donor to the anthraquinone acceptor, Fig. 4(a)).

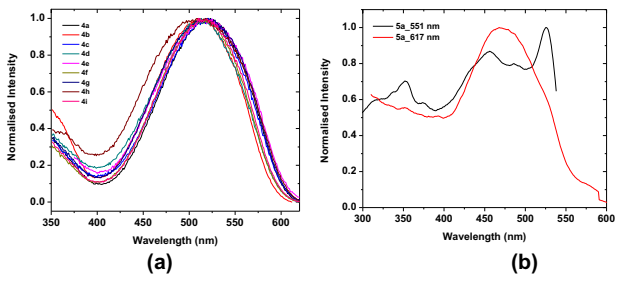


Fig. 4. Excitation spectrum of (a) **4a**–**i** and (b) **5a**.

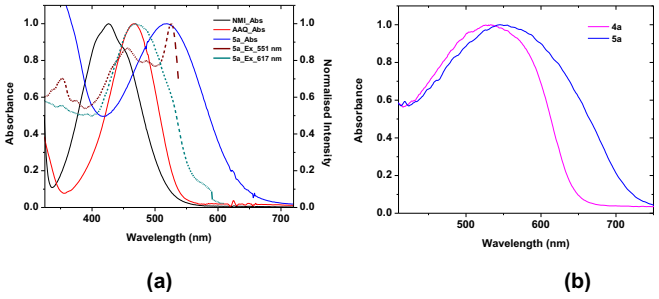


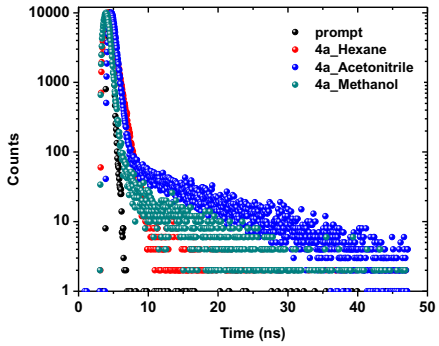
Fig. 5. Absorption spectra of *N*-methylisatin (NMI), 1-aminoanthraquinone (AAQ), **5a** and excitation spectrum of **5a** monitored at 551 nm and 617 nm (a) and diffused reflectance spectra of **4a** and **5a** (b).

To have a clear picture about the nature of the emitting species, time resolved fluorescence studies were carried out using TCSPC technique by exciting the sample at an excitation wavelength of 375 nm. Monitoring the fluorescence decay at 635 nm, compound **4a** showed biexponential behavior with a lifetime of 0.396 ns (0.93) and 6.47 ns (0.07). The longer component in fluorescence decay (6.47 ns) is attributed to the LE state and the shorter component (0.396 ns) may be due to the intramolecular hydrogen bonding existing between carbonyl oxygen and secondary amine in the anthraquinone moiety.

1-Aminoanthraquinone and its derivatives are well known for their radiationless deactivation process through intramolecular hydrogen bonding in nonpolar/polar aprotic solvents and through intermolecular hydrogen bonding with polar protic solvents.[23] To know the role of hydrogen bonding in the present study, we carried out the time resolved fluorescence studies in non-polar and polar protic solvents. In hexane compound **4a** shows single exponential behavior with a lifetime of 0.698 ns due to the radiationless deactivation process provided by intramolecular hydrogen bonding, similarly in methanol it shows single exponential behavior with a lifetime of 0.318 ns due to the intermolecular hydrogen bonding in methanol (Table 3). The above observation reveals that both the intramolecular and intermolecular hydrogen bonding deactivates the excited state of **4a** by radiationless decay pathway. Since acetonitrile is a polar aprotic solvent it reduces the intramolecular hydrogen bonding by interacting with the hydrogen in the secondary amine and hence the decrease in the extent of nonradiative decay pathway, which results in biexponential behavior. In the case of compound **5a** monitoring the fluorescence lifetime decay at both 550 nm and 620 nm showed triexponential behavior and Table 4 presents the fluorescence lifetime of compound **5a** in various solvents.

The shorter component (~0.4–0.9 ns) is attributed to either the intramolecular hydrogen bonding in nonpolar solvent/polar aprotic solvents or the intermolecular hydrogen bonding with the polar protic solvents. The longer component (~6–10 ns) is attributed to the locally excited state, which found to have greater pre-exponential factor, which indicates that the radiationless deactivation pathway is hindered, i.e., the molecular structure is not favoring the intramolecular hydrogen bonding.

Table 3
Fluorescence lifetime decay of **4a** in various solvents



Solvent	Lifetime (ns)		Relative amplitude	
	τ_1	τ_2	*A*1	*A*2
Hexane	0.698	—	1	—
CH_3CN	0.396	6.47	0.93	0.07
MeOH	0.318	—	1	—

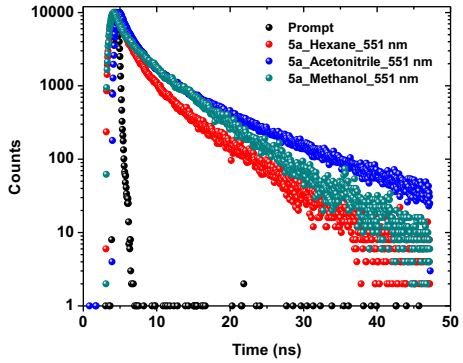
In compound **4a** the spiro ring carbonyl decreases the electron density around the secondary amine and hence it favors the intramolecular hydrogen bonding by increasing the acidity of the amino nitrogen. Whereas in case of **5a**, the electron withdrawing group is far away from the secondary amine and hence the intramolecular hydrogen bonding is not facilitated, which results in poor radiationless deactivation pathway (Fig. 6). However in methanol the intermolecular hydrogen bonding induces the radiationless deactivation process, which is clearly evident from its fluorescence decay profile. Introducing another hydrogen bonding donor group ($-NH_2$) may enhance the radiationless deactivation process and to explore phenomena, compound **5l** synthesized and showed no emission because its excited state is completely deactivated by nonradiative decay process. Another lifetime component (~1.7–3 ns) may be attributed to the aminoanthraquinone fluorophore, which is responsible for the dual emission in the steady state emission spectrum. Though compounds **4a** and **5a** showed very close absorption maxima (519 and 521 nm) in solution and 533 and 546 nm in solid state (Fig. 5(b)), they differ in their color, one is pink and another is violet. Both in solution and solid state, compound **4a** showed only a strong absorption band whereas compound **5a** showed broad absorption band. The fluorescence excitation spectrum revealed that compound **4a** has got one absorption band at 520 nm whereas compound **5a** has got two strong absorption bands at 460 nm and 520 nm (Fig. 4). Hence, although their absorption maxima for compounds **4a** and **5a** are almost the same but their absorption behavior are different and hence the difference in color has been seen.

Absorption and emission data, Stokes shift, fluorescence quantum yield, and fluorescence lifetimes of all the compounds (**4a**–**i** and **5a**–**l**) have been determined (Table 5). Solvatochromism of **4a** and **5a** have been explored for absorption and fluorescence studies (See Supplementary data). Compliments to the new compounds and possible application as fluorophores absorbing at longer wavelength with emission at red or near infrared could exhibit advantages, such as low scattering, deep penetration, minimal interfering absorption, and fluorescence from biological systems.[24]

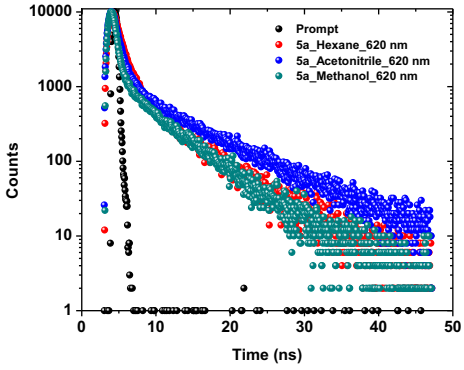
3. Conclusion

We have developed a novel and efficient copper catalyzed synthesis of a number of highly conjugated regioisomers of 3-spiroheterocyclic 2-oxindoles **4a**–**i** and **5a**–**l** via multicomponent reaction of isatins, aryl alkynes, and 1-aminoanthraquinone. The unusual reactivity of 1-aminoanthraquinone provided structurally unique oxindoles as possible fluorophores. Remarkably, this new class of compounds has large Stokes shifts and pronounced fluorescence in orange-red region. Based on experimental observation, a plausible reaction mechanism has been proposed. The final compounds have also been found core structure of many drug molecules.

Table 4
Fluorescence lifetime data of **5a** monitored at 550 nm (a) and 620 nm (b) in various solvents



(a)



(b)

Solvent	Monitored at 550 nm					
	Lifetime (ns)			Relative amplitude		
	τ_1	τ_2	τ_3	*A*1	*A*2	*A*3
Hexane	0.945	2.3	7.58	0.20	0.47	0.33
CH_3CN	0.751	2.42	9.59	0.15	0.38	0.47
MeOH	0.467	2.16	6.2	0.11	0.24	0.66
Solvent	Monitored at 620 nm					
	Lifetime (ns)			Relative amplitude		
	τ_1	τ_2	τ_3	*A*1	*A*2	*A*3
Hexane	0.701	1.73	6.68	0.39	0.33	0.28
CH_3CN	0.494	1.92	10.57	0.14	0.15	0.71
MeOH	0.407	3.04	7.39	0.51	0.19	0.30

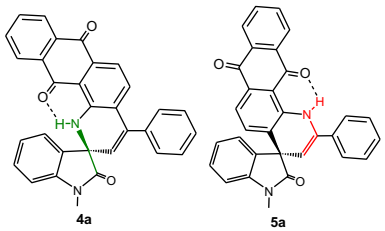


Fig. 6. Possible intramolecular hydrogen bonding in compounds **4a** and **5a**.

Table 5
Selected absorption and emission data, Stokes shifts, fluorescence quantum yields and fluorescence lifetimes of **4a**–**i** and **5a**–**l** (recorded in acetonitrile, T=298 K)

Compound	Absorption[a] λ_{max}, [nm] (log ε)	Emission λ_{max}, [nm]	Quantum yield (ϕ_f)[b]	Stokes shift $\Delta\bar{\nu}$ (cm^{-1})[c]	Fluorescence lifetimes[d] τ_1 [ns]
4a	249 (4.59), 519 (3.93)	635	0.020	3409	0.396 (0.93), 6.47 (0.07)
5a	252 (4.90), 332 (3.93), 521 (3.93)	551, 617	0.006	827	0.751 (0.15), 2.42 (0.38), 9.59 (0.47)
4b	249 (4.88), 330 (4.47), 514 (4.10)	622	0.023	3454	0.511 (0.91) 3.68 (0.09)
5b	252 (4.84), 334 (4.03) 517 (3.87)	589	0.005	2364	0.631 (0.19) 2.86 (0.24) 6.61 (0.57)
4c	248 (5.15), 517 (4.43)	634	0.013	3569	0.428 (0.91) 3.20 (0.89)
5c	252 (4.83), 336 (4.02), 528 (3.86)	551, 597	0.002	719	0.876 (0.25) 2.35 (0.41) 8.40 (0.34)
4d	253 (4.75), 511 (3.83)	630	0.014	3620	0.407 (0.81) 1.58 (0.08) 6.60 (0.11)
5d	252 (4.84), 338 (3.98), 521 (3.86)	549, 603	0.002	979	0.375 (0.26) 2.01 (0.39) 6.33 (0.35)
4e	251 (4.68), 513 (3.99)	622	0.016	3570	0.050 (0.22) 0.45 (0.73) 3.56 (0.05)
5e	251 (4.84), 331 (4.01), 518 (3.85)	635	0.003	1254	0.496 (0.25) 1.79 (0.30) 5.84 (0.45)
4f	257 (4.82), 518 (4.12)	630	0.019	3507	0.378 (0.68) 0.63 (0.22) 4.42 (0.10)
5f	252 (4.93), 336 (3.94), 527 (3.89)	549, 603	0.002	866	0.545 (0.28) 2.08 (0.35) 6.73 (0.37)
4g	249 (4.71), 523 (3.94)	634	0.015	3348	0.341 (0.78) 1.50 (0.10) 8.87 (0.12)
5g	252 (4.92), 333 (4.04), 534 (3.83)	552, 602	0.002	611	0.578 (0.12) 2.28 (0.57) 6.84 (0.31)
4h	248 (4.63), 516 (3.96)	589	0.014	3645	0.044 (0.21) 0.39 (0.73) 1.49 (0.06)
5h	251 (4.67), 334 (3.77), 517 (3.68)	551, 617	0.005	3082	0.491 (0.23) 1.33 (0.18) 8.37 (0.59)
4i	255 (4.65), 514 (3.83)	634	0.015	3545	0.330 (0.58) 1.22 (0.32) 6.80 (0.10)
5i	253 (4.83), 336 (3.89), 534 (3.81)	551, 597	0.004	3070	0.475 (0.27) 1.81 (0.46) 6.04 (0.27)
5j	253 (4.66), 513 (3.73)	634	0.005	3390	0.843 (0.27) 1.77 (0.30) 7.69 (0.43)
5l	251 (4.37), 606 (3.53)	—	—	—	—

[a] Recorded for the concentration of 10^{-5} mol/L.
[b] Rhodamine 6G in ethanol as standard.
[c] Stoke shift=$\lambda_{max,abs}-\lambda_{max,emi}$ [cm^{-1}].
[d] Determined by time correlated single photon counting at an excitation wavelength of 375 nm and monitored at their respective emission maximum.

4. Experimental section

4.1. Typical experimental procedure

A mixture of *N*-methylisatin **1a** (161 mg, 1 mmol, 1 equiv), phenylacetylene **2a** (0.12 mL, 1 mmol, 1.2 equiv), 1-aminoanthraquinone (0.266 g, 1 mmol, 1.2 equiv) **3a**, cuprous chloride (9.9 mg, 10 mol %), and copper(II) triflate (36.1 mg, 10 mol %) in dry toluene (4 mL) was refluxed at 120 °C for 24 h under nitrogen atmosphere. The progress of the reaction was monitored by TLC. After completion of the reaction, the mixture was cooled to room temperature, filtered through a pad of neutral alumina using ethyl acetate as a solvent. The solvent was evaporated in vacuo and the residue was chromatographed on neutral alumina using gradient elution of hexane/ethyl acetate as solvent to yield compounds **4a** as pink powder, 183 mg, 39% yield and **5a** as violet powder, 197 mg, 42% yield.

*4.1.1. (R)-1-Methyl-4′-phenyl-1′H-spiro[indoline-3,2′-naphtho[2,3-h]quinoline]-2,7′,12′-trione (**4a**).* Pink crystals: mp 210 °C; 183 mg, 39% yield; R_f (30% EtOAc/Hexane) 0.51; IR (KBr) λ_{max}: 3438, 2927, 1725, 1657, 1622, 1485, 1341, 1274, 1131, 1021, 722 cm^{-1}; ^{1}H NMR ($CDCl_3$/TMS, 500.1 MHz): δ 3.24 (s, 3H), 5.44 (d, J=2.3 Hz, 1H), 6.89 (d, J=7.65 Hz, 1H), 7.14 (t, J=7.65 Hz, 1H), 7.29 (d, J=8.4 Hz, 1H), 7.34–7.42 (m, 6H), 7.53–7.57 (m, 2H), 7.70–7.75 (m, 2H), 8.18 (d, J=7.65 Hz, 1H), 8.25 (d, J=7.65 Hz, 1H), 10.35 (s, 1H); ^{13}C NMR ($CDCl_3$/TMS, 125.7 MHz): δ 26.8, 64.2, 108.8, 112.9, 117.4, 123.4, 123.9, 125.5, 126.4, 126.7, 126.9, 128.4, 128.7, 129.0, 130.4, 131.5, 133.2, 133.3, 133.9, 133.9, 134.9, 137.6, 139.0, 142.24, 147.9, 175.2, 182.9, 185.3; HRMS (ESI-TOF) m/z: $[M]^+$ calcd for $C_{31}H_{20}N_2O_3$ 468.1474; found 468.1482.

*4.1.2. (R)-1-Methyl-2′-phenyl-1′H-spiro[indoline-3,4′-naphtho[2,3-h]quinoline]-2,7′,12′-trione (**5a**).* Violet crystals: 295 °C; 197 mg, 42% yield; R_f (30% EtOAc/Hexane) 0.50; IR (KBr) λ_{max}: 3438, 3064, 2928, 1717, 1662, 1590, 1495, 1333, 1271, 1088, 995, 748 cm^{-1}; ^{1}H NMR ($CDCl_3$/TMS, 500.1 MHz): δ 3.31 (s, 3H), 4.90 (s, 1H), 6.91 (d, J=7.65 Hz, 1H), 6.95 (d, J=7.65 Hz, 1H), 7.09 (t, J=7.65 Hz, 1H), 7.25 (d, J=4.6 Hz, 1H), 7.35 (t, 8.4 Hz, 1H), 7.41 (d, J=6.85 Hz, 1H), 7.46 (t, J=7.65 Hz, 2H) 7.69 (d, J=7.65 Hz, 3H), 7.76 (t, J=7.65 Hz, 1H), 7.81 (t, J=7.65 Hz, 1H), 8.25 (d, J=7.65 Hz, 1H), 8.34 (d, J=7.65 Hz, 1H), 11.67 (s, 1H); ^{13}C NMR ($CDCl_3$/TMS, 125.7 MHz): δ 26.9, 53.9, 97.4, 108.5, 120.2, 123.9, 125.4, 125.6, 127.0, 127.1, 128.4, 129.0, 129.1, 129.2, 132.9, 133.7, 133.8, 134.3, 134.4, 134.5, 135.3, 138.1, 138.4, 142.3, 142.4, 178.6, 182.9, 186.4; HRMS (ESI-TOF) m/z: $[M]^+$ calcd for $C_{31}H_{20}N_2O_3$ 468.1474; found 468.1491.

*4.1.3. (R)-1-Methyl-5-nitro-4′-phenyl-1′H-spiro[indoline-3,2′-naphtho[2,3-h]quinoline]-2,7′,12′-trione (**4b**).* Pink powder, 216 mg, 42% yield; R_f (30% EtOAc/Hexane) 0.47; IR (KBr) λ_{max}: 3448, 2925, 1740, 1662, 1612, 1489, 1336, 1274, 1052, 723 cm^{-1}; ^{1}H NMR ($CDCl_3$/TMS, 500.1 MHz): δ 3.31 (s, 3H), 5.39 (d, J=2.3 Hz, 1H), 6.99 (d, J=8.4 Hz, 1H), 7.32–7.36 (m, 3H), 7.40–7.43 (m, 3H), 7.60 (d, J=7.65 Hz, 1H), 7.74 (t, J=3.8 Hz, 2H), 8.15–8.17 (m, 1H), 8.25–8.26 (m, 1H), 8.35 (dd, J=8.4, 2.25 Hz, 1H), 8.45 (d, J=2.3 Hz, 1H), 10.40 (s, 1H); ^{13}C NMR ($CDCl_3$/TMS, 125.7 MHz): δ 27.2, 63.8, 108.6, 113.3, 117.8, 121.2, 121.6, 125.6, 126.8, 127.1, 127.4, 128.7, 128.8, 128.9, 132.0, 133.3, 133.7, 133.9, 134.1, 134.6, 137.0, 140.1, 144.4, 147.1, 147.8, 175.4, 182.8, 185.7; HRMS (ESI-TOF) m/z: $[M]^+$ calcd for $C_{31}H_{19}N_3O_5$ 513.1325; found 513.1325.

*4.1.4. (R)-1-Methyl-5-nitro-2′-phenyl-1′H-spiro[indoline-3,4′-naphtho[2,3-h]quinoline]-2,7′,12′-trione (**5b**).* Violet powder, 232 mg, 45% yield; R_f (30% EtOAc/Hexane) 0.46; IR (KBr) λ_{max}: 3437, 2925, 1731, 1664, 1605, 1495, 1334, 1271, 1058, 995, 748 cm^{-1}; ^{1}H NMR ($CDCl_3$/TMS, 500.1 MHz): δ 3.39 (s, 3H), 4.82 (s, 1H), 6.87 (d, J=7.65 Hz, 1H), 7.05 (d, J=8.4 Hz, 1H), 7.44–7.50 (m, 3H), 7.69 (d, J=6.85 Hz, 2H), 7.72 (d, J=7.6 Hz, 1H), 7.77–7.84 (m, 2H), 8.14 (d, J=1.55 Hz, 1H), 8.26 (d, J=7.65 Hz, 1H), 8.32–8.36 (m, 2H), 11.72 (s, 1H); ^{13}C NMR ($CDCl_3$/TMS, 125.7 MHz): δ 27.3, 53.8, 95.3, 108.2, 120.3, 121.6, 125.5, 126.2, 126.4, 127.1, 127.2, 129.1, 129.6, 132.9, 134.1, 134.4, 134.5, 134.9, 138.6, 139.5, 141.9, 144.4, 147.9, 165.9, 178.7, 182.7, 186.5; HRMS (ESI-TOF) m/z: $[M]^+$ calcd for $C_{31}H_{19}N_3O_5$ 513.1325; found 513.1338.

*4.1.5. (R)-1,5-Dimethyl-4′-phenyl-1′H-spiro[indoline-3,2′-naphtho[2,3-h]quinoline]-2,7′,12′-trione (**4c**).* Pink powder, 184 mg, 38% yield; R_f (30% EtOAc/Hexane) 0.54; IR (KBr) λ_{max}: 3441, 2925, 1724, 1660, 1627, 1492, 1347, 1274, 1099, 1020, 721 cm^{-1}; ^{1}H NMR ($CDCl_3$/TMS, 500.1 MHz): δ 2.33 (s, 3H), 3.22 (s, 3H), 5.44 (s, 1H), 6.78 (d, J=8.05 Hz, 1H), 7.17 (d, J=8.0 Hz, 1H), 7.29 (d, J=8.05 Hz, 1H), 7.35–7.42 (m, 6H), 7.56 (d, J=8.0 Hz, 1H), 7.70–7.75 (m, 2H), 8.18 (d,

J=6.9 Hz, 1H), 8.25 (d, *J*=7.41 Hz, 1H), 10.35 (s, 1H); ^{13}C NMR ($CDCl_3$/TMS, 125.7 MHz): 21.1, 26.8, 64.3, 108.6, 112.8, 117.4, 123.7, 126.3, 126.4, 126.7, 126.9, 128.4, 128.7, 129.0, 130.7, 131.4, 133.2, 133.3, 133.7, 133.8, 134.0, 134.9, 137.6, 138.8, 139.8, 147.9, 175.2, 182.9, 185.3; HRMS (ESI-TOF) *m*/*z*: $[M]^+$ calcd for $C_{32}H_{22}N_2O_3$ 482.1630; found 482.1645.

*4.1.6. (R)-1,5-Dimethyl-2′-phenyl-1′H-spiro[indoline-3,4′-naphtho[2,3-h]quinoline]-2,7′,12′-trione (**5c**).* Violet powder, 193 mg, 40% yield; R_f (30% EtOAc/Hexane) 0.53; IR (KBr) λ_{max}: 3430, 3065, 2925, 1715, 1666, 1629, 1589, 1496, 1466, 1270, 1094, 994, 807, 736 cm^{-1}; ^{1}H NMR ($CDCl_3$/TMS, 500.1 MHz): δ 2.27 (s, 3H), 3.29 (s, 3H), 4.91 (d, *J*=2.3 Hz, 1H), 6.82 (d, *J*=8.4 Hz, 1H), 6.91 (d, *J*=7.6 Hz, 1H), 7.07 (s, 1H), 7.13 (d, *J*=7.65 Hz, 1H), 7.38–7.46 (m, 3H), 7.67–7.79 (m, 5H), 8.22 (d, *J*=7.65 Hz, 1H), 8.31 (d, *J*=7.65 Hz, 1H), 11.66 (m, 1H). ^{13}C NMR ($CDCl_3$/TMS, 125.7 MHz): 21.2, 26.9, 54.0, 97.7, 108.2, 114.7, 120.2, 125.4, 126.3, 126.9, 127.1, 128.7, 129.0, 129.2, 129.4, 132.9, 133.6, 133.7, 133.8, 134.3, 134.5, 135.30, 138.2, 138.3, 139.9, 142.3, 178.6, 182.9, 186.4; HRMS (ESI-TOF) *m*/*z*: $[M]^+$ calcd for $C_{32}H_{22}N_2O_3$ 482.1630; found 482.1643.

*4.1.7. (R)-5-Iodo-1-methyl-4′-phenyl-1′H-spiro[indoline-3,2′-naphtho[2,3-h]quinoline]-2,7′,12′-trione (**4d**).* Pink powder 238 mg, 40% yield; R_f (30% EtOAc/Hexane) 0.56; IR (KBr) λ_{max}: 3432, 2925, 1727, 1659, 1630, 1598, 1484, 1334, 1273, 1098, 721 cm^{-1}; ^{1}H NMR ($CDCl_3$/TMS, 500.1 MHz): δ 3.22 (s, 3H), 5.40 (s, 1H), 6.68 (d, *J*=8.05 Hz, 1H), 7.30 (d, *J*=7.45 Hz, 1H), 7.35 (d, *J*=7.45 Hz, 2H), 7.39–7.42 (m, 3H), 7.58 (d, *J*=8 Hz, 1H), 7.69–7.75 (m, 3H), 7.81 (s, 1H), 8.19 (d, *J*=6.85 Hz, 1H), 8.25 (d, *J*=6.9 Hz, 1 H), 10.35 (s, 1H). ^{13}C NMR ($CDCl_3$/TMS, 125.7 MHz): δ 26.8, 64.0, 86.3, 110.9, 113.0, 117.6, 122.5, 126.0, 126.8, 127.0, 128.5, 128.7, 128.9, 131.7, 133.3, 133.5, 133.9, 134.1, 134.3, 134.8, 135.2, 137.3, 139.3, 139.4, 141.9, 147.5, 174.5, 182.9, 185.5. HRMS (ESI-TOF) *m*/*z*: $[M]^+$ calcd for $C_{31}H_{19}IN_2O_3$ 594.0440; found 594.0457.

*4.1.8. (R)-5-Iodo-1-methyl-2′-phenyl-1′H-spiro[indoline-3,4′-naphtho[2,3-h]quinoline]-2,7′,12′-trione (**5d**).* Violet powder 250 mg, 42% yield; R_f (30% EtOAc/Hexane) 0.55; IR (KBr) λ_{max}: 3427, 2927, 1719, 1631, 1663, 1590, 1487, 1329, 1269, 1093, 994, 748, 719 cm^{-1}; ^{1}H NMR ($CDCl_3$/TMS, 500.1 MHz): δ 3.28 (s, 3H), 4.85 (s, 1H), 6.72 (d, *J*=8.4 Hz, 1H), 6.89 (d, *J*=8.4 Hz, 1H), 7.41–7.48 (m, 3H), 7.52 (d, *J*=1.5 Hz, 1H), 7.65 (d, *J*=8.4 Hz, 1H), 7.69 (t, *J*=7.65 Hz, 3H), 7.73–7.80 (m, 2H), 8.23 (d, *J*=7.65 Hz, 1H), 8.31 (d, *J*=7.6 Hz, 1H), 11.66 (s, 1H); ^{13}C NMR ($CDCl_3$/TMS, 125.7 MHz): δ 26.9, 53.8, 86.3, 96.5, 110.6, 114.9, 120.3, 125.4, 127.1, 127.1, 127.5, 132.9, 133.9, 134.3, 135.1, 137.9, 138.7, 140.2, 142.1, 177.9, 182.8, 186.4; HRMS (ESI-TOF) *m*/*z*: $[M]^+$ calcd for $C_{31}H_{19}IN_2O_3$ 594.0440; found 594.0452.

*4.1.9. (R)-1-Methyl-4′-phenyl-5-(trifluoromethoxy)-1′H-spiro[indoline-3,2′-naphtho[2,3-h]quinoline]-2,7′,12′-trione (**4e**).* Pink powder 216 mg, 39% yield; R_f (30% EtOAc/Hexane) 0.47; IR (KBr) λ_{max}: 3438, 2928, 1732, 1660, 1628, 1490, 1264, 1165, 720 cm^1; ^{1}H NMR ($CDCl_3$/TMS, 500.1 MHz): δ 3.25 (s, 3H), 5.42 (s, 1H), 6.89 (d, *J*=8.4 Hz, 1H), 7.26–7.28 (m, 1H), 7.31 (d, *J*=8.4 Hz, 1H), 7.35 (d, *J*=8.4 Hz, 2H), 7.39–7.44 (m, 3H), 7.45 (s, 1H), 7.58 (d, *J*=8.4 Hz, 1H), 7.71–7.77 (m, 2H), 8.18 (d, *J*=6.85 Hz, 1H), 8.25 (d, *J*=6.9 Hz, 1H), 10.36 (s, 1H). ^{13}C NMR ($CDCl_3$/TMS, 125.7 MHz): δ 26.9, 64.3, 109.4, 113.1, 117.6, 119.5, 122.3, 123.6, 126.0, 126.8, 127.0, 128.5, 128.7, 128.9, 131.7, 133.3, 133.5, 133.9, 134.1, 134.5, 134.7, 137.3, 139.6, 140.9, 145.7, 147.5, 175.1, 182.9, 185.5; HRMS (ESI-TOF) *m*/*z*: $[M+Na]^+$ calcd for $C_{32}H_{19}F_3N_2O_4Na$ 575.1194; found 575.1195.

*4.1.10. (R)-1-Methyl-2′-phenyl-5-(trifluoromethoxy)-1′H-spiro[indoline-3,4′-naphtho[2,3-h]quinoline]-2,7′,12′-trione (**5e**).* Violet powder 254 mg, 46% yield; R_f (30% EtOAc/Hexane) 0.46; IR (KBr) λ_{max}: 3444, 1724, 1667, 1630, 1587, 1495, 1467, 1264, 1166, 1096, 717 cm^1; ^{1}H NMR ($CDCl_3$/TMS, 500.1 MHz): δ 3.31 (s, 3H), 4.86 (s, 1H), 6.89 (d, *J*=7.65 Hz, 1H), 6.94 (d, *J*=8.4 Hz, 1H), 7.17 (s, 1H), 7.23 (d, *J*=8.45 Hz, 1H), 7.43 (d, *J*=7.65 Hz, 1H), 7.47 (t, *J*=7.65 Hz, 2H), 7.70 (t, *J*=7.68.45 Hz, 3H), 7.74–7.81 (m, 2H), 8.24 (d, *J*=7.65 Hz, 1H), 8.32 (d, *J*=7.65 Hz, 1H), 11.68 (s, 1H); ^{13}C NMR ($CDCl_3$/TMS, 125.7 MHz): δ 27.0, 54.2, 96.3, 109.0, 119.6, 120.3, 122.3, 125.5, 127.1, 127.2, 127.3, 128.4, 129.1, 129.4, 132.9, 133.9, 134.3, 134.4, 135.1, 138.9, 139.2, 141.1, 142.1, 145.7, 178.4, 182.8, 186.5; HRMS (ESI-TOF) *m*/*z*: $[M+Na]^+$ calcd for $C_{32}H_{19}F_3N_2O_4Na$ 575.1194; found 575.1182.

*4.1.11. (R)-5-Bromo-1-methyl-4′-phenyl-1′H-spiro[indoline-3,2′-naphtho[2,3-h]quinoline]-2,7′,12′-trione (**4f**).* Pink powder 209 mg, 38% yield; R_f (30% EtOAc/Hexane) 0.55; IR (KBr) λ_{max}: 3441, 3064, 2926, 1729, 1658, 1482, 1274, 1099, 1021, 810, 718 cm^{-1}; ^{1}H NMR ($CDCl_3$/TMS, 500.1 MHz): δ 3.23 (s, 3H), 5.41 (s, 1H), 6.78 (d, *J*=8.4 Hz, 1H), 7.31 (d, *J*=7.65 Hz, 1H), 7.35 (d, *J*=7.65 Hz, 2H), 7.40–7.45 (m, 3H), 7.51 (d, *J*=8.4 Hz, 1H), 7.58 (d, *J*=7.65 Hz, 1H), 7.66 (s, 1H), 7.72–7.77 (m, 2H), 8.19 (d, *J*=9.15 Hz, 1H), 8.25 (d, *J*=6.85 Hz, 1H), 10.36 (s, 1H); ^{13}C NMR ($CDCl_3$/TMS, 125.7 MHz): δ 26.9, 64.2, 110.4, 113.0, 116.5, 117.5, 122.4, 126.0, 126.8, 127.0, 128.5, 128.7, 128.8, 128.9, 131.7, 133.3, 133.5, 133.9, 134.1, 134.8, 134.9, 137.3, 139.4, 141.3, 147.5, 165.9, 174.7, 182.8, 185.5; HRMS (ESI-TOF) *m*/*z*: $[M+Na]^+$ calcd for $C_{31}H_{19}BrN_2O_3Na$ 571.0456; found 571.0806.

*4.1.12. (R)-5-Bromo-1-methyl-2′-phenyl-1′H-spiro[indoline-3,4′-naphtho[2,3-h]quinoline]-2,7′,12′-trione (**5f**).* Violet powder 247 mg, 45% yield; R_f (30% EtOAc/Hexane) 0.54; IR (KBr) λ_{max}: 3435, 3066, 2927, 1721, 1663, 1591, 1487, 1328, 1269, 1095, 995, 750, 718 cm^{-1}; ^{1}H NMR ($CDCl_3$/TMS, 500.1 MHz): δ 3.29 (s, 3H), 4.86 (s, 1H), 6.83 (d, *J*=8.4 Hz, 1H), 6.90 (d, *J*=7.65 Hz, 1H), 7.37 (d, *J*=1.5 Hz, 1H), 7.42 (d, *J*=6.9 Hz, 1H), 7.45–7.48 (m, 3H), 7.70 (t, *J*=9.15 Hz, 3H), 7.74–7.81 (m, 2H), 8.24 (d, *J*=7.65 Hz, 1H), 8.32 (d, *J*=6.9 Hz, 1H), 11.67 (s, 1H); ^{13}C NMR ($CDCl_3$/TMS, 125.7 MHz): δ 26.9, 54.0, 96.5, 110.0, 114.9, 116.4, 120.3, 125.4, 127.1, 127.2, 127.5, 128.8, 129.1, 129.4, 132.0, 132.9, 133.9, 134.3, 134.4, 134.4, 135.1, 138.8, 139.8, 141.4, 142.1, 178.1, 182.8, 186.5; HRMS (ESI-TOF) *m*/*z*: $[M+Na]^+$ calcd for $C_{31}H_{19}BrN_2O_3Na$ 571.0456; found 571.0806.

*4.1.13. (R)-1-Methyl-4′-p-tolyl-1′H-spiro[indoline-3,2′-naphtho[2,3-h]quinoline]-2,7′,12′-trione (**4g**).* Pink powder 169 mg, 35% yield; R_f (30% EtOAc/Hexane) 0.55; IR (KBr) λ_{max}: 3437, 2926, 1725, 1661, 1613, 1486, 1369, 1341, 1274, 1018, 753, 722 cm^{-1}; ^{1}H NMR ($CDCl_3$/TMS, 500.1 MHz): δ 2.38 (s, 3H), 3.24 (s, 3H), 5.43 (s, 1H), 6.89 (d, *J*=8.4 Hz, 1H), 7.13 (t, *J*=7.65 Hz, 1H), 7.20–7.23 (m, 3H), 7.32 (d, *J*=7.65 Hz, 1H) 7.37 (t, *J*=6.9 Hz, 1H), 7.54 (t, *J*=8.4 Hz, 2H), 7.67–7.73 (m, 3H), 8.16 (d, *J*=6.9 Hz, 1H), 8.23 (d, *J*=7.65 Hz, 1H), 10.35 (s, 1H). ^{13}C NMR ($CDCl_3$/TMS, 125.7 MHz): δ 21.4, 26.8, 64.2, 108.8, 112.9, 117.4, 123.1, 123.9, 125.5, 126.6, 126.7, 126.9, 128.9, 129.3, 130.4, 131.5, 133.2, 133.3, 134.0, 134.6, 134.9, 138.2, 138.9, 142.2, 147.9, 175.3, 182.9, 185.3; HRMS (ESI-TOF) *m*/*z*: $[M]^+$ calcd for $C_{32}H_{22}N_2O_3$ 482.1630; found 482.1621.

*4.1.14. (R)-1-Methyl-2′-p-tolyl-1′H-spiro[indoline-3,4′-naphtho[2,3-h]quinoline]-2,7′,12′-trione (**5g**).* Violet powder 188 mg, 39% yield; R_f (30% EtOAc/Hexane) 0.54; IR (KBr) λ_{max}: 3443, 2925, 1718, 1668, 1589, 1497, 1466, 1336, 1270, 1088, 750, 718 cm^{-1}; ^{1}H NMR ($CDCl_3$/TMS, 500.1 MHz): δ 2.39 (s, 3H), 3.31 (s, 3H), 4.86 (s, 1H), 6.90 (d, *J*=8.4 Hz, 1H), 6.95 (d, *J*=8.4 Hz, 1H), 7.09 (t, *J*=7.65 Hz, 1H), 7.26–7.27 (m, 2H), 7.35 (t, *J*=7.65 Hz, 1H), 7.58 (d, *J*=7.63 Hz, 2H), 7.68 (d, *J*=7.65 Hz, 1H), 7.74–7.80 (m, 3H), 8.25 (d, *J*=7.65 Hz, 1H), 8.34 (d, *J*=7.65 Hz, 1H), 11.64 (s, 1H); ^{13}C NMR ($CDCl_3$/TMS, 125.7 MHz): δ 21.4, 26.9, 53.9, 96.7, 108.4, 120.1, 123.9, 125.3, 125.6, 127.0, 127.1, 128.5, 129.1, 129.7, 132.4, 132.9, 133.7, 133.8, 134.3, 134.4, 134.5, 138.2, 138.3, 139.2, 142.4, 178.7, 182.9, 186.4 HRMS (ESI-TOF) *m*/*z*: $[M]^+$ calcd for $C_{32}H_{22}N_2O_3$ 482.1630; found 482.1647.

*4.1.15. (R)-4′-(4-Fluorophenyl)-1-methyl-1′H-spiro[indoline-3,2′-naphtho[2,3-h]quinoline]-2,7′,12′-trione (**4h**).* Pink powder 161 mg, 33% yield; R_f (30% EtOAc/Hexane) 0.53; IR (KBr) λ_{max}: 3438, 2929,

1725, 1659, 1612, 1486, 1341, 1275, 1154, 1092, 844, 724 cm^{-1}; ^1H NMR ($CDCl_3$/TMS, 500.1 MHz): δ 3.25 (s, 3H), 5.43 (d, J=1.5 Hz, 1H), 6.90 (d, J=7.65 Hz, 1H), 7.10 (t, J=8.4 Hz, 2H), 7.15 (t, J=7.65 Hz, 1H), 7.25 (d, J=7.65 Hz, 1H), 7.33 (dd, J=5.35, 3.1 Hz, 2H), 7.39 (t, J=7.65 Hz, 1H), 7.54 (d, J=6.85 Hz, 1H), 7.57 (d, J=7.6 Hz, 1H), 7.70–7.75 (m, 2H), 8.17 (d, J=6.85 Hz, 1H), 8.25 (d, J=7.6 Hz, 1H), 10.34 (s, 1H). ^{13}C NMR ($CDCl_3$/TMS, 125.7 MHz): δ 26.8, 64.15, 108.9, 112.9, 115.6, 115.8, 117.4, 123.6, 123.9, 125.5, 126.2, 126.7, 127.0, 130.5, 130.7, 130.8, 131.3, 133.0, 133.3, 133.4, 133.5, 133.9, 134.1, 134.8, 138.1, 142.22, 147.8, 164.8 (d, J=272.16 Hz, C–F coupling), 175.2, 182.9, 185.3; HRMS (ESI-TOF) m/z: $[M+Na]^+$ calcd for $C_{31}H_{19}FN_2O_3Na$ 509.1277; found 509.1245.

*4.1.16. (R)-2′-(4-Fluorophenyl)-1-methyl-1′H-spiro[indoline-3,4′-naphtho[2,3-h]quinoline]-2,7′,12′-trione (**5h**).* Violet powder 195 mg, 40% yield; R_f (30% EtOAc/Hexane) 0.52; IR (KBr) λ_{max}: 3435, 3067, 2928, 1715, 1663, 1598, 1496, 1332, 1272, 1161, 1091, 997, 841, 748 cm^{-1}; ^1H NMR ($CDCl_3$/TMS, 500.1 MHz): δ 3.31 (s, 3H), 4.83 (s, 1H), 6.90 (d, J=8.4 Hz, 1H), 6.95 (d, J=7.65 Hz, 1H), 7.10 (t, J=7.65 Hz, 1H), 7.14 (t, J=8.4 Hz, 2H), 7.26 (d, J=7.65 Hz, 1H), 7.36 (t, J=7.65 Hz, 1H), 7.65–7.69 (m, 3H), 7.73–7.80 (m, 2H), 8.23 (d, J=7.6 Hz, 1H), 8.30 (d, J=7.65 Hz, 1H), 11.61 (s, 1H). ^{13}C NMR ($CDCl_3$/TMS, 125.7 MHz): δ 26.9, 53.9, 97.3, 108.5, 114.8, 115.9, 116.1, 120.3, 123.9, 125.6, 127.1, 127.1, 127.3, 127.3, 128.3, 129.2, 131.5, 132.9, 133.7, 133.9, 134.3, 134.4, 134.6, 137.6, 138.0, 142.2, 142.4, 163.3 (d, J=248.19 Hz, C–F coupling), 178.6, 182.9, 186.5; HRMS (ESI-TOF) m/z: $[M+Na]^+$ calcd for $C_{31}H_{19}FN_2O_3Na$ 509.1277; found 509.1268.

*4.1.17. (R)-4′-(4-Methoxyphenyl)-1-methyl-1′H-spiro[indoline-3,2′-naphtho[2,3-h]quinoline]-2,7′,12′-trione (**4i**).* Pink powder 170 mg, 34% yield; R_f (30% EtOAc/Hexane) 0.51; IR (KBr) λ_{max}: 3434, 3066, 2932, 1722, 1660, 1611, 1484, 1275, 1022, 837, 722 cm^{-1}; ^1H NMR ($CDCl_3$/TMS, 500.1 MHz): δ 3.24 (s, 3H), 3.83 (s, 3H), 5.42 (d, J=1.5 Hz, 1H), 6.89 (d, J=8.4 Hz, 1H), 6.93 (d, J=8.4 Hz, 2H), 7.14 (t, J=7.6 Hz, 1H), 7.27 (d, J=9.15 Hz, 2H), 7.33 (d, J=7.65 Hz, 1H), 7.38 (t, J=7.65 Hz, 1H), 7.53 (d, J=7.65 Hz, 1H), 7.56 (d, J=7.65 Hz, 1H), 7.69–7.74 (m, 2H), 8.17 (d, J=6.9 Hz, 1H), 8.24 (d, J=6.85 Hz, 1H), 10.34 (s, 1H). ^{13}C NMR ($CDCl_3$/TMS, 125.7 MHz): δ 26.8, 55.4, 64.2, 108.8, 112.9, 114.0, 117.4, 123.0, 123.9, 125.5, 126.7, 126.9, 129.8, 130.2, 130.4, 131.4, 133.2, 133.3, 133.7, 134.0, 134.9, 138.6, 142.2, 147.9, 159.7, 175.3, 182.9, 185.3; HRMS (ESI-TOF) m/z: $[M]^+$ calcd for $C_{32}H_{22}N_2O_4Na$ 521.1477; found 521.1392.

*4.1.18. (R)-2′-(4-Methoxyphenyl)-1-methyl-1′H-spiro[indoline-3,4′-naphtho[2,3-h]quinoline]-2,7′,12′-trione (**5i**).* Violet powder 190 mg, 38% yield; R_f (30% EtOAc/Hexane) 0.50; IR (KBr) λ_{max}: 3429, 2925, 1715, 1609, 1497, 1467, 1335, 1269, 1178, 1090, 1030, 719 cm^{-1}; ^1H NMR ($CDCl_3$/TMS, 500.1 MHz): δ 3.31 (s, 3H), 3.85 (s, 3H), 4.81 (s, 1H), 6.90 (d, J=7.65 Hz, 1H), 6.95 (d, J=8.4 Hz, 1H), 6.98 (d, J=7.6 Hz, 2H), 7.09 (t, J=7.6 Hz, 1H), 7.25 (d, J=7.65 Hz, 1H), 7.35 (t, J=8.0 Hz, 1H), 7.62 (d, J=9.15 Hz, 2H), 7.68 (d, J=7.65 Hz, 1H), 7.74–7.82 (m, 2H), 8.25 (d, J=7.65 Hz, 1H), 8.33 (d, J=7.65 Hz, 1H), 11.62 (s, 1H). ^{13}C NMR ($CDCl_3$/TMS, 125.7 MHz): δ 26.8, 53.9, 55.5, 95.9, 108.4, 114.3, 114.7, 120.1, 123.9, 125.6, 126.7, 127.0, 127.1, 127.8, 128.6, 129.0, 132.9, 133.7, 133.8, 134.3, 134.4, 134.5, 137.9, 138.2, 142.4, 160.3, 178.7, 182.9, 186.4; HRMS (ESI-TOF) m/z: $[M+Na]^+$ calcd for $C_{32}H_{22}N_2O_4Na$ 521.1477; found 521.1868.

*4.1.19. (R)-1-Methyl-2′-(4-(trifluoromethyl)phenyl)-1′H-spiro[indoline-3,4′-naphtho[2,3-h]quinoline]-2,7′,12′-trione (**5j**).* Violet powder 204 mg, 38% yield; R_f (30% EtOAc/Hexane) 0.48; IR (KBr) λ_{max}: 3439, 2932, 1717, 1606, 1495, 1327, 1272, 1165, 1123, 1003, 846, 720 cm^{-1}; ^1H NMR ($CDCl_3$/TMS, 500.1 MHz): δ 3.32 (s, 3H), 4.96 (s, 1H), 6.91 (d, J=8.4 Hz, 1H), 6.97 (d, J=7.65 Hz, 1H), 7.11 (t, J=7.65 Hz, 1H), 7.25 (d, J=6.1 Hz, 1H), 7.37 (t, J=7.65 Hz, 1H), 7.70–7.73 (m, 3H), 7.76–7.83 (m, 4H), 8.25 (d, J=7.65 Hz, 1H), 8.32 (d, J=6.85 Hz, 1H), 11.72 (s, 1H); ^{13}C NMR ($CDCl_3$/TMS, 125.7 MHz): δ 26.8, 53.9, 98.9, 108.6, 114.9, 120.5, 123.9, 125.6, 125.8, 126.0, 126.1, 127.1, 127.1, 128.1, 129.3, 132.9, 133.8, 134.0, 134.4, 134.5, 137.4, 137.8, 138.7, 142.0, 142.4, 178.3, 182.8, 186.6; HRMS (ESI-TOF) m/z: $[M+Na]^+$ calcd for $C_{32}H_{19}F_3N_2O_3Na$ 559.1245; found 559.1232.

*4.1.20. (R)-6′-Amino-1-methyl-2′-phenyl-1′H-spiro[indoline-3,4′-naphtho[2,3-h]quinoline]-2,7′,12′-trione (**5l**).* Violet powder 223 mg, 46% yield; R_f (30% EtOAc/Hexane) 0.43; IR (KBr) λ_{max}: 3423, 3303, 3060, 2926, 2857, 1709, 1605, 1523, 1483, 1346, 1267, 1086, 1022, 748, 699 cm^{-1}; ^1H NMR ($CDCl_3$/TMS, 500.1 MHz): δ 3.33 (s, 3H), 4.91 (s, 1H), 6.32 (s, 1H), 6.94 (d, J=7.5 Hz, 1H), 7.06 (t, J=7.5 Hz, 1H), 7.11–7.15 (m, 2H), 7.22 (d, J=8.5 Hz, 1H), 7.32 (t, J=7.5 Hz, 1H), 7.40 (t, J=7.5 Hz, 1H), 7.46 (t, J=7.5 Hz, 2H), 7.60 (t, J=7.5 Hz, 1H), 7.67 (t, J=7.5 Hz, 1H), 7.74 (d, J=7.5 Hz, 2H), 8.15 (d, J=7.5 Hz, 1H), 8.23 (d, J=7.5 Hz, 1H), 12.36 (s, 1H); ^{13}C NMR ($CDCl_3$/TMS, 125.7 MHz): δ 26.9, 53.9, 96.5, 108.6, 110.8, 112.3, 124.0, 125.3, 125.4, 125.6, 126.4, 127.1, 127.9, 128.1, 128.3, 128.6, 129.0, 129.1, 132.5, 132.6, 132.8, 133.1, 133.9, 134.0, 135.5, 136.3, 137.5, 138.8, 142.0, 146.9, 178.9, 178.5, 183.3, 185.1; HRMS (ESI-TOF) m/z: $[M]^+$ calcd for $C_{31}H_{21}N_3O_3Na$ 506.1480; found 506.1382.

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Supplementary data

Copies of ^1H NMR, ^{13}C NMR, UV–vis, Emission, Excitation spectra, Solvatochromism, Fluorescence lifetime, FTIR and HRMS for all compounds has been provided. Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.tet.2013.02.037.

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