Synthesis of Diphenylamine-Based Novel Fluorescent Styryl Colorants by Knoevenagel Condensation Using a Conventional Method, Biocatalyst, and Deep Eutectic Solvent

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"For Publication"

Table 2. Spectroscopic and thermal properties of compounds a-k

Entry	a	b	c	d	e	f	g	H	i	j	k
λ_{max} nm[a]	525	420	495	510	435	500	475	460	425	385	470
λ_{em} nm[a]	624	586	590	658	524	588	526	530	516	462	564
Stokes shift	99	166	95	148	89	88	51	70	91	77	94
ε l/mol.cm	17117	21258	72458	84918	36635	73992	43668	19384	40612	54023	55533
$T_{d/g}$[a']	314	347	280	328	362	311	325	-	332	274	316

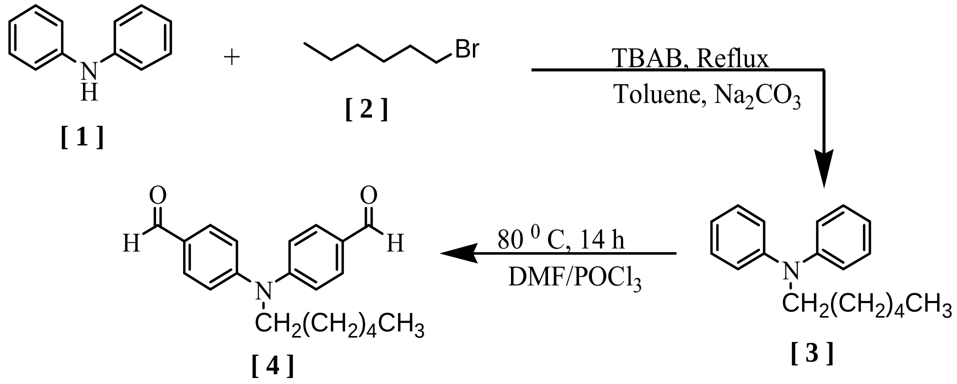
[a] Absorption and photoluminescence spectra of the dyes in dichloromethane (1×10^{-4} M) solution, [a'] Initial decomposition temperature (°C) determined by thermal gravimetric analysis (TGA)

Table 3. Reuse of biocatalyst and deep eutectic solvent

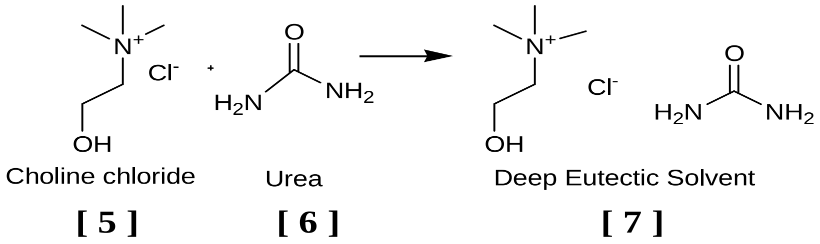
Recycle	Yield [%][b]	Yield [%][c]
Fresh, Non- Recycled	78.5	95.3
First	75	91.5
Second	69	90.7
Third	62.5	92.4
Forth	50.8	85.1
Fifth	-	80.2

[b] : Isolated yield by lipase catalysed reaction, [c] : Isolated yield by deep eutectic solvent, Compound **a** was used for the recycle experiment,

Scheme 1 Synthesis of 4,4'-hexylimino-bisbenzaldehyde **4**



Scheme 2 Preparation of deep eutectic solvent **7**



Materials and equipments

Commercial lipase produced from *Thermomyces lanuginosus* produced by submerged fermentation of genetically modified *Aspergillus oryzae* microorganism and having activity 100 KLU/g, was used for the reactions.All the solvents and chemicals were procured from S D fine chemicals (India) and were used without further purification. The reactions were monitored by TLC using 0.25 mm E-Merck silica gel 60 F_{254} precoated plates, which were visualized with UV light. UV – Visible absorption spectra were recorded on Spectronic genesis 2 spectrophotometer instruments from dye solutions (~ 10^{-4} M) in chloroform. The fluorescence maxima of the same were recorded on Jasco FP-1520 fluorimeter from dye solutions in chloroform. The ^{1}H NMR and ^{13}CNMR spectra were recorded on 400 MHz and100 MHz respectively on Varian mercury plus spectrometer. Chemical shifts are expressed in δ ppm using TMS as an internal standard. Mass spectral data were obtained with micromass - Q – Tof (YA105) spectrometer. Elemental analysis was done on Harieus rapid analyzer. Melting points measured and thermogravimetric analysis were carried out on SDT Q600 v8.2 Build 100 model of TA instruments.

Experimental

Synthesis of N-hexyl-N-phenylbenzenamine 3

1-Bromohexane **9** (43.87 g, 265 mmol), diphenylamine **8** (20 g, 118 mmol), sodium carbonate (30.7 g, 289 mmol), TBAB (2 g, 10%) and toluene (150 mL) were placed in a 500 mL two neck round-bottom flask. This mixture was stirred for 36 h at reflux temperature. The resulted mixture was extracted with ethyl acetate and dried over $MgSO_4$. After filtering, the solvent was evaporated. The resulting yellowish liquid[20] was obtained after purification by column chromatography (mobile phase-hexane, 60-120 mesh silica gel). Yield 22.44 g (61 %); 1H NMR, ($CDCl_3$, δ ppm, 300 MHz): 0.87 (t, 3H), 1.28-1.40 (m, 6H), 1.63 (m, 2H), 3.65 (t, 2H), 6.91-6.95 (d, 4H, aromatic, J = 7.33 Hz), 6.98 (dd, 2H, J = 7.63 Hz), 7.22-7.29 (d, 4H, J = 7.33 Hz), MS (ES+): *m/z* 253.2 calcd for found 254.1 (M+1); Anal. calcd for $C_{18}H_{23}N$: C, 85.32; H, 9.15; N, 5.53; found: C, 85.59; H, 8.98.; N, 5.71;

Synthesis of 4,4'-hexylimino-bisbenzaldehyde 4

In a 500 mL three neck round bottom flask (26.2 mL, 340 mmol) of anhydrous N,N-dimethylformamide was cooled (0-5 ^{O}C) in an ice bath. To, this solution, (25.6 mL, 279 mmol) of phosphorous oxychloride was added dropwise for 30 min. at 0-5 ^{O}C. N-hexyl-N-phenylbenzenamine **10** (7 g, 27.85 mmol) was added to the above solution and heated to 80^0 C for 14 h. This solution was then cooled to room temperature, poured in to ice water, and neutralized to pH 6-7 by dropwise addition of saturated aqueous sodium hydroxide solution. The mixture was extracted with dichloromethane. The organic layer was dried with anhydrous $MgSO_4$ and then concentrated on rotary evaporator. The crude product on purification by column chromatography (mobile phase- hexane: ethyl acetate, 50:50, and silica gel 60-120 mesh). afforded yellowish liquid. Yield 5.6g, (65%); 1H NMR, ($CDCl_3$, δ ppm, 300 MHz): 0.88 (t, 3H), 0.9 (m, 2H), 1.3 (m, 4H), 1.7 (m, 2H), 3.84 (t, 2H), 7.15-7.18 (d, 4H, aromatic), 7.80-7.83 (d, 4H, aromatic), 9.89 (s,2H, aldehyde proton), *Anal.* calcd for $C_{20}H_{23}NO_2$: C, 77.64; H, 7.49; N, 4.53; found: C, 77.74; H, 7.68.; N, 4.64. MS: *m/z* calcd for 309.17 found 310.2 (M+1).

Preparation of deep eutectic solvent (choline chloride:urea)[23] 3

Choline chloride (100 g, 71 mmol) and urea (86 g, 140 mmol) were placed in a round bottom flask and heated to 70 to 80°C, until liquid began to form. After 15 to 20 min, a homogenous colorless liquid (186 g, 100%) formed, which was used directly for the reactions without purification.

Synthesis of chromophores a-k

Synthesis of chromophores a-k by conventional Knoevenagel condensation

A mixture of 4,4'hexyliminobisbenzaldehyde (3.1 mmol) and different active methylene compound (6.2 mmol) in absolute ethanol (25 mL), piperidine (3-4 drops) was stirred at reflux temperature. The reaction was monitored by TLC. After completion of the reaction, the precipitated solid was filtered, and washed with ethanol. In case of compounds **h**, **i** and **j**, were extracted in dichloromethane and solvent was removed under reduced vacuum to obtain liquid product. Crude compounds purified by column chromatography (mobile phase: Toluene, 100-200 mesh silica gel)

Synthesis of chromophores a-k by using biocatalyst

In typical experimental procedure to 15 ml of absolute ethanol, (3.1 mmol) (for dialdehyde) of active methylene (6.2 mmol) compound were added. The ratio of aldehyde to active methylene compound (m/m) 1:1.01 for monoaldehyde and 1:2.02 for dialdehyde. The reaction mass was cleared in ethanol and was initiated by adding 50 mg (10% wt. by wt. of aldehyde) Lipase. The reaction mixture was stirred at 60ºC. The reaction was monitored by using TLC. The reaction mass was filtered to remove catalyst and cooled the reaction mass to get precipitation of product. Then filtered the reaction mass washed with (2 ml) ethanol for removal of excess active methylene compound and unreacted aldehyde. In case of compounds **h**, **i** and **j**, were extracted in dichloromethane and solvent was removed under reduced vacuum to obtain liquid product.

Synthesis of chromophores a-k by using deep eutectic solvent

A mixture of 4,4’hexyliminobisbenzaldehyde (3.1mmol) and different active methylene compound (6.2 mmol) was added to the deep eutectic solvent (5 ml) with stirring for 15 min, room temperature. The reaction was monitored by TLC. After completion of the reaction, water was added, the mixture filtered, and residual product dried in an oven under vacuum. In case of compounds **h**, **i** and **j**, were extracted in dichloromethane and solvent was removed under reduced vacuum to obtain liquid product.

Synthesis of 2,2'-(3,3'-(1E,1'E)-2,2'-(4,4'-(hexylazanediyl)bis(4,1-phenylene))bis(ethene-2,1-diyl)bis(5,5-dimethylcyclohex-2-ene-3-yl-1-ylidene))dimalononitrile a

Red colored solid. Melting point (measured) 182^{o}C λmax (Dichloromethane)/nm 525; ^{1}H NMR (400 MHz, $CDCl_3$, TMS) δH; 0.88 (t, 3H), 1.08 (s, 12H), 1.29-1.33 (m, 8H), 1.65 (m, 2H), 3.77 (t, 2H), 6.81 (s, 2H), 7.03 (d, 2H, J = 8.86 Hz), 7.24 (d, 4H, J = 7.63 Hz), 7.43 (d, 2H, J = 15.9 Hz), 7.02 (d, 2H, J = 15.88 Hz), ^{13}C NMR (100 MHz, $CDCl_3$, TMS) δ 14.15, 22.75, 26.80, 27.67, 28.17, 32.16, 39.34, 43.12, 43.56, 52.49, 77.52, 113.95, 116.19, 121.17, 123.58, 125.58, 126.49, 127.87, 129.17, 130.66, 131.81, 136.91, 148.58, 154.52, 169.34, 190.43; *Anal.* calcd for $C_{44}H_{47}N_5$: C, 81.81; H, 7.33; N, 10.84; found: C, 81.62; H, 7.58.; N, 11.02. MS: *m/z* calcd for 645.87 found 644.53 (M-1). FTIR ν_{max}/cm^{-1} 2956, 2869, 2214, 1716, 1541, 1500, 1176.

Synthesis of (E)-2-cyano-2-(3-(4-((4-formylphenyl)(hexyl)amino)styryl)-5,5-dimethylcyclohex-2-enylidene)acetamide b

Red colored solid. Melting point (measured) 163^{o}C λmax (Dichloromethane)/nm 420; ^{1}H NMR (100 MHz, CDCl$_3$, TMS) δH; 0.88 (t, 3H), 1.03-1.08 (s, 12H), 1.12-1.33 (m, 6H), 1.58 (m, 2H), 3.78 (t, 2H), 6.83-6.85 (d, 4H, J = 8.55 Hz), 7.20 (d, 4H, J = 8.24 Hz), 7.51 (d, 1H, olefinic proton), 7.70 (1H, olefinic proton), 8.05 (s, 1H), 9.77 (s, 1H, aldehydic proton); ^{13}C NMR (100 MHz, CDCl$_3$, TMS) δ 14.07, 22.67, 26.69, 27.84, 28.27, 28.41, 31.59, 39.29, 45.05, 52.63, 99.66, 115.17, 118.80, 124.99, 126.55, 127.45, 128.31, 129.94, 130.76, 131.80, 133.38, 146.54, 150.72, 152.91, 163.30, 164.06, 190.37; *Anal.* calcd for $C_{32}H_{37}N_3O_2$: C, 77.54; H, 7.52; N, 8.48; found: C, 77.62; H, 7.48.; N, 8.22. MS: *m/z* calcd for 495.65 found 496.20 (M+1). FTIR ν_{max}/cm^{-1} 3334, 2950, 2194, 1670, 1587, 1502, 1361, 1163.

(2E,2'E)-2,2'-(3,3'-(1E,1'E)-2,2'-(4,4'-(hexylazanediyl)bis(4,1-phenylene))bis(ethene-2,1-diyl)bis(5,5-dimethylcyclohex-2-ene-3-yl-1-ylidene))bis(2-cyanoacetamide) c

Brown colored solid. Melting point (measured) 189^{o}C; λmax (Dichloromethane)/nm 495; ^{13}C NMR (100 MHz, CDCl$_3$, TMS) δ 14.14, 22.75, 26.82, 27.66, 28.49, 31.70, 39.02, 39.35, 45.17, 52.45, 98.49, 119.16, 121.08, 124.12, 122.09, 128.69, 129.70, 131.74, 134.37, 151.73, 163.78, 165.85; *Anal.* calcd for $C_{44}H_{51}N_5O_2$: C, 77.50; H, 7.54; N, 10.27; found: C, 77.31; H, 7.48.; N, 10.15. MS: *m/z* calcd for 681.90 found 682.56 (M+1).

(2E,2'E)-2,2'-(3,3'-(1E,1'E)-2,2'-(4,4'-(hexylazanediyl)bis(4,1-phenylene))bis(ethene-2,1-diyl)bis(5,5-dimethylcyclohex-2-ene-3-yl-1-ylidene))bis(2-(benzo[d]thiazol-2-yl)acetonitrile) d

Brown colored solid. λmax (Dichloromethane)/nm 510; ^{1}H NMR (400 MHz, CDCl$_3$, TMS) δH; 0.88 (t, 3H), 1.10 (s, 12H), 1.31-1.39 (m, 6H), 1.69 (m, 2H), 2.44 (s, 2H), 2.74 (s, 2H), 3.12 (s, 2H), 3.77 (t, 2H), 6.94 (d, 4H, J = 14.96 Hz), 6.97 (s, 2H), 7.02 (m, 4H, J = 6.41 Hz), 7.44 (d, 4H), 7.51 (m, 4H, J = 7.33 Hz), 7.91 (dd, 2H, J = 7.63 Hz), 8.06 (dd, 2H, J = 8.24 Hz); ^{13}C NMR (100 MHz, CDCl$_3$, TMS) δ 14.21, 22.21, 22.81, 25.70, 26.63, 26.89, 28.70, 31.71, 32.05, 39.09, 101.1, 118.19, 121.13, 121.46, 123.45, 123.56, 125.64, 126.66, 128.44, 128.63, 129.01, 129.82, 133.41, 135.23, 148.08, 150.17, 154.00, 158.15; *Anal.* calcd for $C_{56}H_{55}N_5S_2$: C, 78.01; H, 6.43; N, 8.12; S, 7.44; found: C, 77.89; H, 6.26.; N, 8.36; S, 7.12 MS: *m/z* calcd for 862.20 found 862.60 (M+1). FTIR ν_{max}/cm^{-1} 2839, 2217, 1500.

(2E,2'E)-3,3'-(4,4'-(hexylazanediyl)bis(4,1-phenylene))bis(2-(thiophen-2-yl)acrylonitrile) e

Orange-red colored solid. Melting poin 132^{o}C λmax (Dichloromethane)/nm 435; ^{1}H NMR (400 MHz, CDCl$_3$, TMS) δH; 0.89 (t, 3H), 1.32-1.36 (m, 6H), 1.69 (m, 2H), 3.80 (t, 2H), 7.05-7.07 (dd, 4H, J = 8.55 Hz), 7.11 (d, 4H, J = 8.85 Hz), 7.26 (d, 2H, J = 7.02 Hz), 7.30 (s, 2H, olefinic proton), 7.35 (dd, 2H), 7.83 (d, 4H, J = 8.55 Hz), *Anal.* calcd for $C_{32}H_{29}N_3S_2$: C, 73.94; H, 5.62; N, 8.09; S, 12.34; found: C, 73.72; H, 5.27.; N, 8.01; S, 12.24 MS: *m/z* calcd for 519.72 found 520.27 (M+1). FTIR ν_{max}/cm^{-1} 2925, 2214, 1577, 1500, 1367, 1249, 1180.

(2E,2'E)-diethyl 2,2'-(3,3'-(1E,1'E)-2,2'-(4,4'-(hexylazanediyl)bis(4,1-phenylene))bis(ethene-2,1-diyl)bis(5,5-dimethylcyclohex-2-ene-3-yl-1-ylidene))bis(2-cyanoacetate) f
Brown solid. λmax (Dichloromethane)/nm 500;^{1}H NMR (400 MHz, $CDCl_3$, TMS) δH; 0.87 (t, 3H), 1.07 (s, 12H), 1.31-1.36 (m, 6H), 1.37-1.39 (t, 6H), 1.68 (m, 2H), 2.64 (s, 4H), 2.99 (s, 4H), 3.76 (t, 2H), 4.28 (m, 4H), 6.91 (d, 4H, J = 8.25 Hz),7.00-7.03 (d, 4H, J = 15 Hz, olefinic proton), 7.40-7.40 (d, 4H, J = 8.85 Hz), 7.92 (s, 2H); *Anal.* calcd for $C_{48}H_{57}N_3O_4$: C, 77.91; H, 7.76; N, 5.68; found: C, 77.67; H, 7.54.; N, 5.39; MS: *m/z* calcd for 739.98 found 740.10 (M+1). FTIR ν_{max}/cm^{-1} 3351, 2927, 2217, 1714, 1562, 1447, 1178.

2,2'-(4,4'-(hexylazanediyl)bis(4,1-phenylene)bis(methan-1-yl-1-ylidene))dimalononitrile g
Orange-red colored solid. Melting point 154^{o}C λmax (Dichloromethane)/nm 475; ^{1}H NMR (400 MHz, $CDCl_3$, TMS) δH; 0.88 (t, 3H), 1.30-1.32 (m, 6H), 1.69 (m, 2H), 3.88 (t, 2H), 7.19 (d, 4H, J = 8.85 Hz), 7.63 (s, 2H), 7.89 (d, 4H, J = 8.85 Hz); ^{13}C NMR (100 MHz, $CDCl_3$, TMS) δ 14.10, 22.68, 26.68, 27.73, 31.55, 52.77, 78.86, 113.5, 114.61, 121.26, 125.40, 133.16, 151.36, 158..07; *Anal.* calcd for $C_{26}H_{23}N_5$: C, 77.01; H, 5.72; N, 17.27; found: C, 76.;82 H, 5.63.; N, 17.45; MS: *m/z* calcd for 405.50 found 406.40 (M+1). FTIR ν_{max}/cm^{-1} 3132, 1662, 1596, 1552, 1490, 1337, 1296.

(2E,2'E)-diethyl3,3'-(4,4'-(hexylazanediyl)bis(4,1-phenylene))bis(2-cyanoacrylate) h
Yellowish orange colored liquid. λmax (Dichloromethane)/nm 460; ^{1}H NMR (400 MHz, $CDCl_3$, TMS) δH; 0.88 (t, 3H), 1.10 (s, 12H), 1.31-1.39 (m, 6H), 1.69 (m, 2H), 2.44 (s, 4H), 3.12 (s, 4H), 3.77 (t, 2H), 6.94 (d, 4H, J = 14.96 Hz, olefinic proton), 6.97 (s, 2H), 7.02 (d, 4H, J = 6.41 Hz), 7.44 (d, 4H), 7.51 (m, 4H, J = 7.33 Hz), 7.91 (dd, 2H, J = 7.63 Hz), 8,06 (dd, 2H, J = 8.24 Hz); ^{13}C NMR (100 MHz, $CDCl_3$, TMS) δ 14.01, 14.27, 22.61, 26.63, 27.61, 31.51, 52.53, 62.49, 99.48, 116.36, 120.95, 125.47, 133.28, 150.61, 153.70, 163.19; *Anal.* calcd for $C_{30}H_{33}N_3O_4$: C, 72.12; H, 6.66; N, 8.41; found: C, 72.37; H, 6.48.; N, 8.23; MS: *m/z* calcd for 499.60 found 500.12 (M+1).

(2Z,2'Z)-3,3'-(4,4'-(hexylazanediyl)bis(4,1-phenylene))bis(2-phenylacrylonitrile) i
Orange colored liquid. λmax (Dichloromethane)/nm 425; ^{1}H NMR (400 MHz, $CDCl_3$, TMS) δH; 0.88 (t, 3H), 1.31-1.33 (m, 4H), 1.56 (m, 2H), 1.70 (m, 2H), 3.82 (t, 2H), 7.12 (d, 4H, J = 8.55 Hz), 7.37 (dd, 2H, J = 7.33and 2.13 Hz), 7.42 (d, 4H, J = 8.85 Hz), 7.67 (dd, 2H, J = 7.63 and 1.22 Hz), 7.88 (dd, 2H, J = 8.85 Hz), 7.26 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$, TMS) δ 14.14, 22.74, 26.76, 27.63, 31.65, 52.42, 103.08, 117.59, 120.85, 125.65, 126.47, 126.89, 128.18, 130.84, 139.19, 139.85, 148.72; *Anal.* calcd for $C_{36}H_{33}N_3$: C, 85.17; H, 6.55; N, 8.28; found: C, 84.91; H, 6.36.; N, 8.16; MS: *m/z* calcd for 507.66 found 508.30 (M+1). FTIR ν_{max}/cm^{-1} 3029, 2925, 2264, 1519, 1504, 1361, 1180, 757.

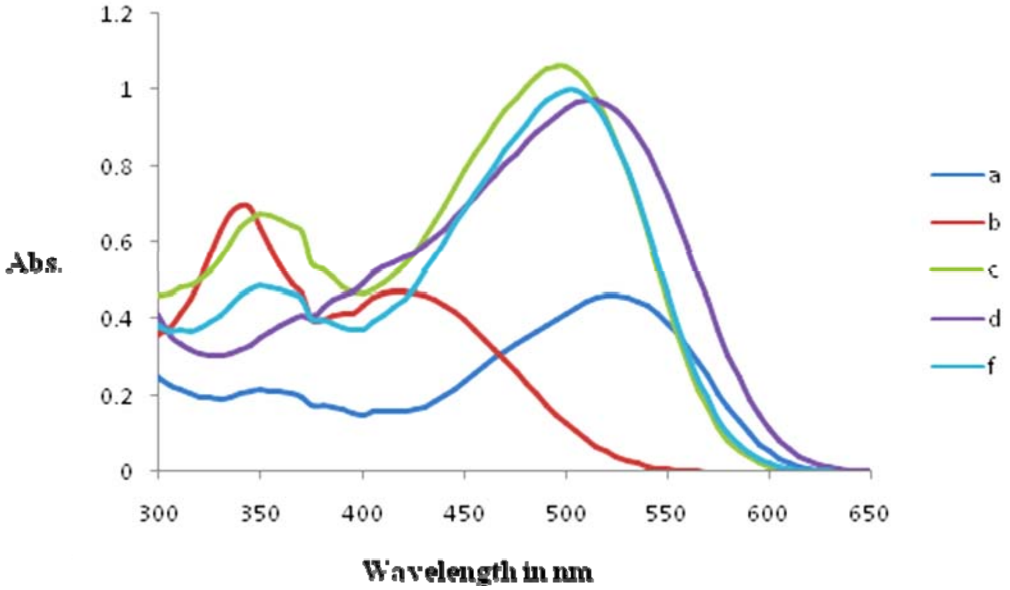
(Z)-3-(4-((4-formylphenyl)(hexyl)amino)phenyl)-2-(4-methoxyphenyl)acrylonitrile j

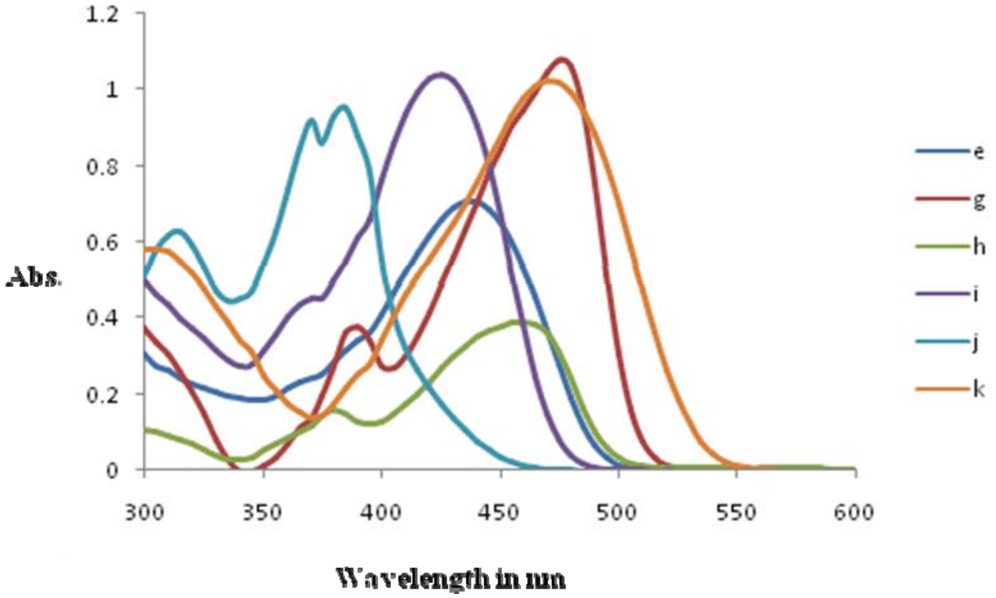
Orange colored liquid. λmax (Dichloromethane)/nm 385; ^{1}H NMR (400 MHz, $CDCl_3$, TMS) δH; 0.88 (t, 3H), 1.29-1.31 (m, 6H), 1.66 (m, 2H), 3.81 (t, 2H), 3.86 (s, 3H), 7.18 (d, 2H, J = 8.55 Hz), 7.24 (d, 2H, J = 7.63 Hz), 7.62 (d, 2H, J = 8.85 Hz), 7.82 (d, 2H, J = 8.85), 7.91 (d, 2H, J = 8.55 Hz), 7.41 (s, 1H), 9.89 (s, 1H, aldehydic proton); *Anal.* calcd for $C_{29}H_{30}N_2O_2$: C, 79.42; H, 6.89; N, 6.39; found: C, 79.67; H, 6.68.; N, 6.13; MS: *m/z* calcd for 438.56 found 439.30 (M+1). FTIR ν_{max}/cm^{-1} 2925, 2854, 2206, 1687, 1561, 1504, 1361, 1180.

(2Z,2'Z)-3,3'-(4,4'-(hexylazanediyl)bis(4,1-phenylene))bis(2-(4-nitrophenyl)acrylonitrile) k
Red colored solid. Melting point 179°C λmax (Dichloromethane)/nm 470; ^{1}H NMR (400 MHz, $CDCl_3$, TMS) δH; 0.88 (t, 3H), 1.32-1.38 (m, 6H), 1.71 (m, 2H), 3.88 (t, 2H), 7.19 (d, 4H, J = 8.85 Hz), 7.61 (s, 2H, olefinic proton), 7.82 (d, 4H, J = 9.16 Hz), 7.84 (d, 4H, J = 7.02), 8.30 (d, 4H, J = 8.85 Hz); ^{13}C NMR (100 MHz, $CDCl_3$, TMS) δ 14.14, 22.75, 26.80, 31.68, 50.35, 106.31, 117.99, 121.07, 124.52, 126.78, 131.85, 141.25, 144.60, 147.68, 149.64; *Anal.* calcd for $C_{36}H_{31}N_5O_4$: C, 72.35; H, 5.23; N, 11.72; found: C, 72.09; H, 5.48.; N,11.41; MS: *m/z* calcd for 597.66 found 597.80. FTIR ν_{max}/cm^{-1} 2931, 2210, 1571, 1504, 1334.

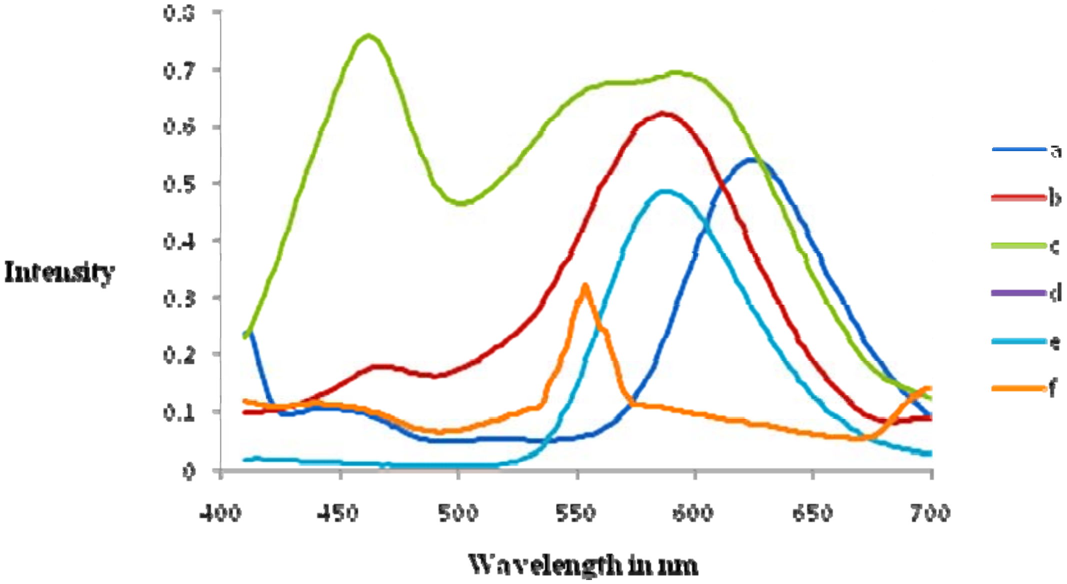
Photophysical analysis

Absorption and photoluminescence spectra of the dyes in dichloromethane (1×10^{-4} M) solution

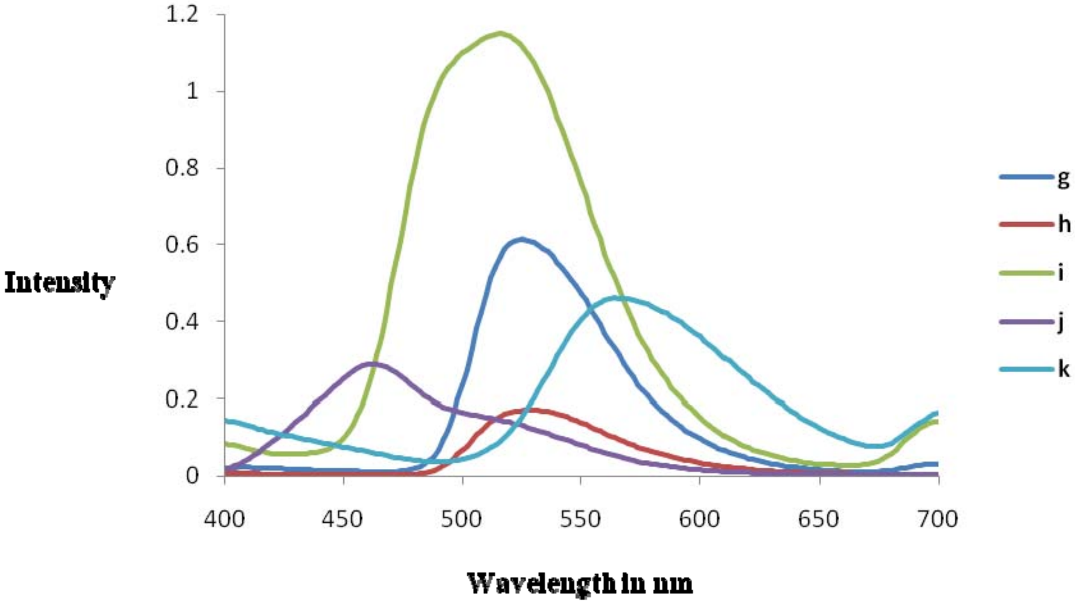




Emission of compounds a-f

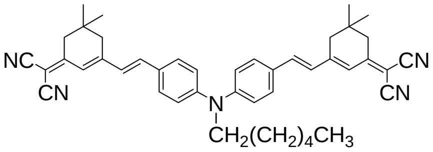


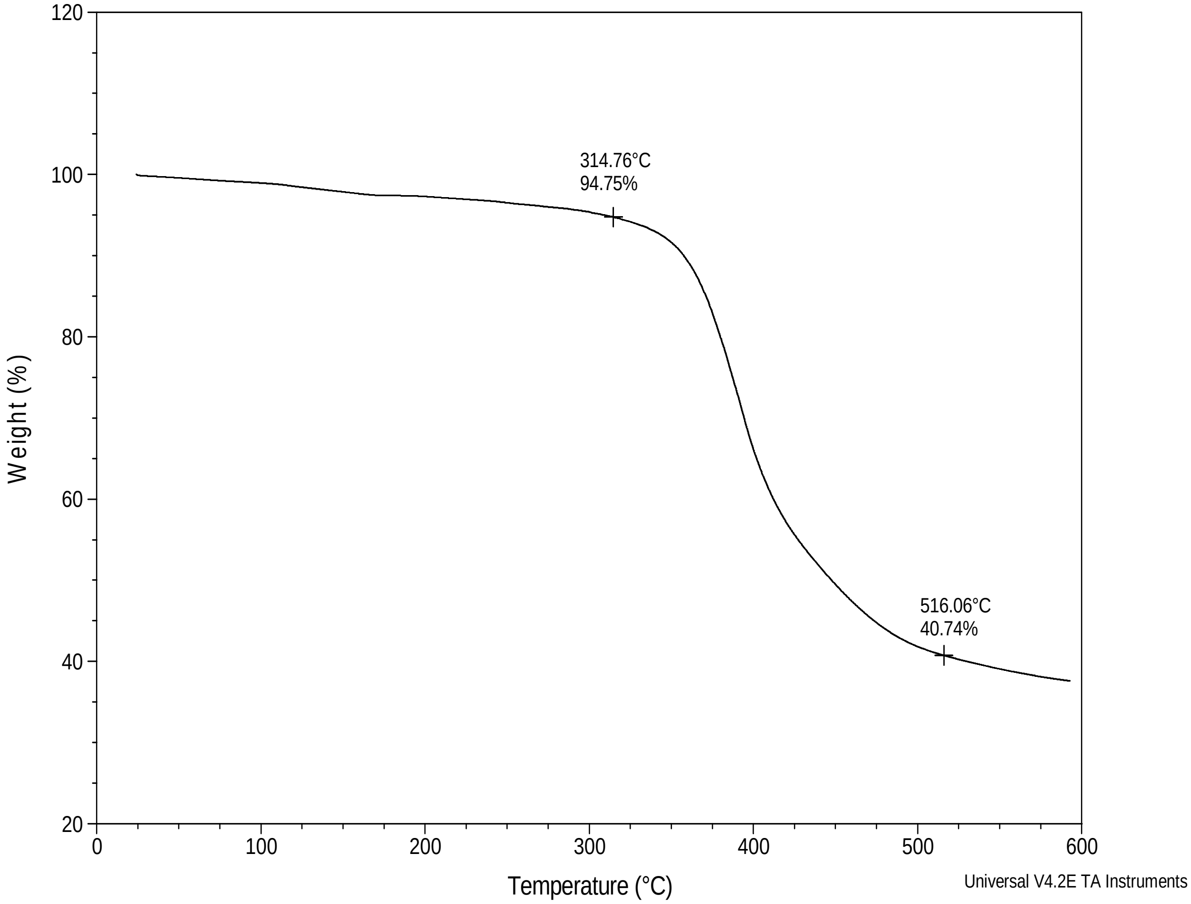
Emission of compound g-k



Thermal stability of compounds a-k

Thermal stability of a





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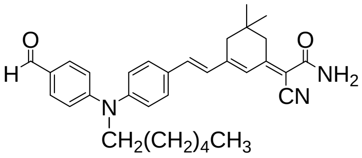
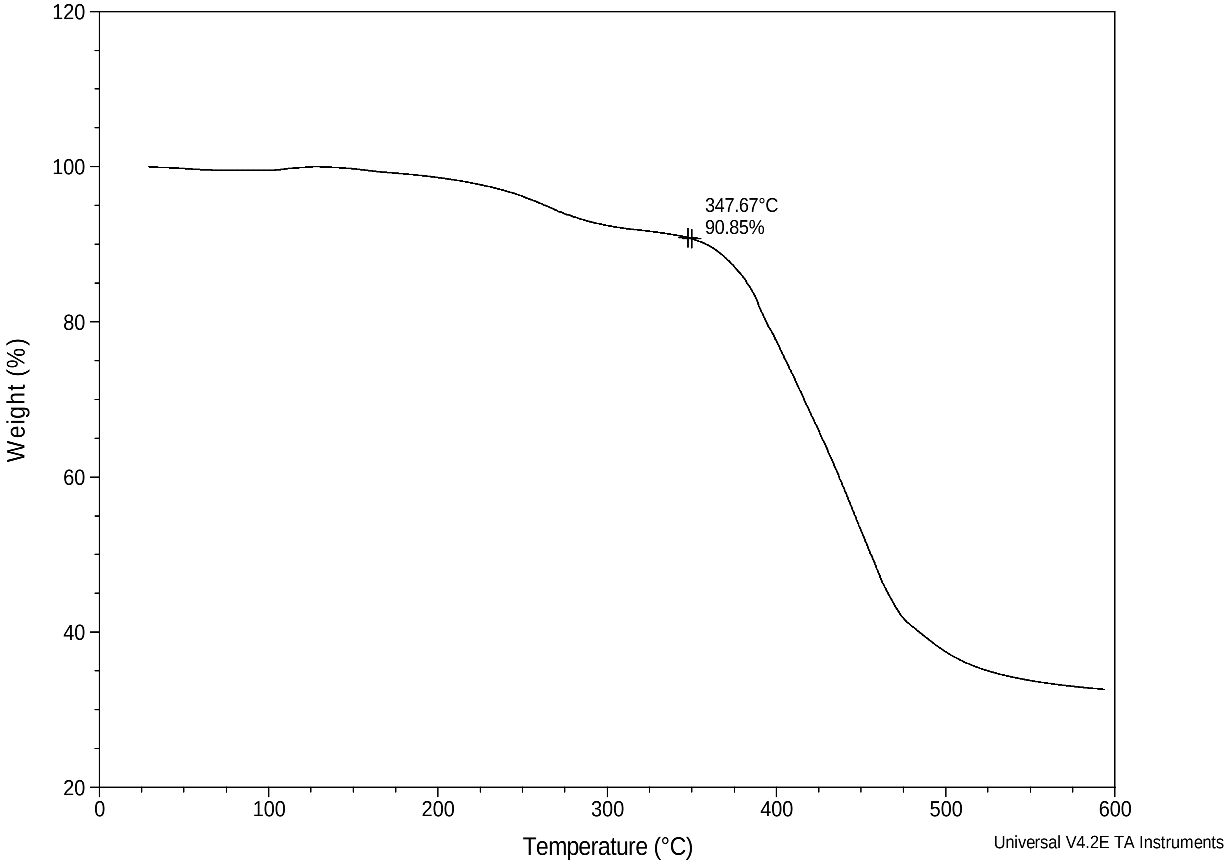
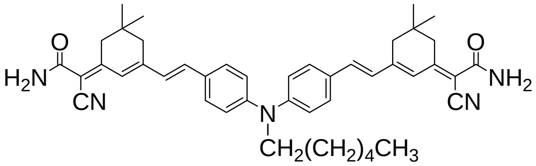
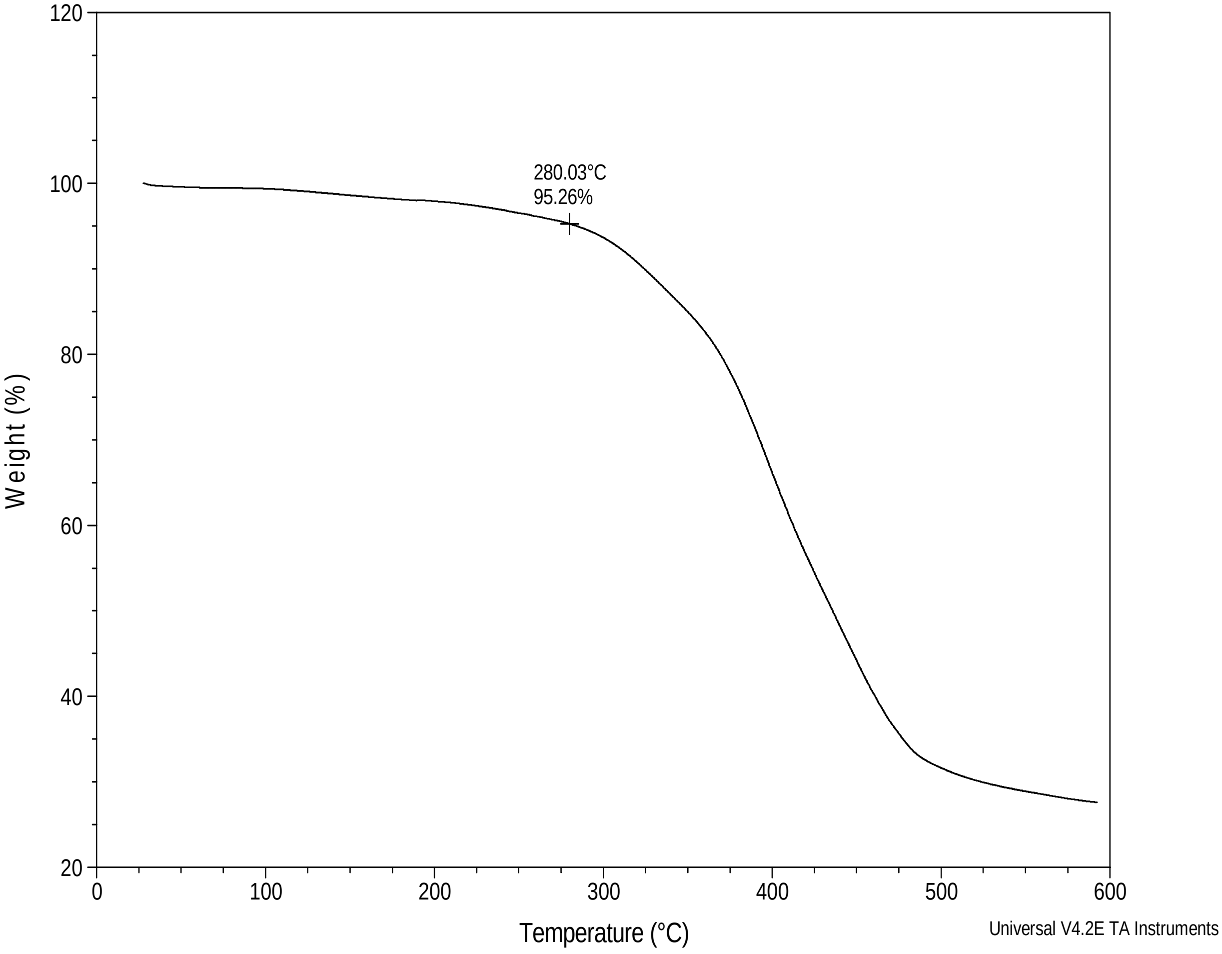


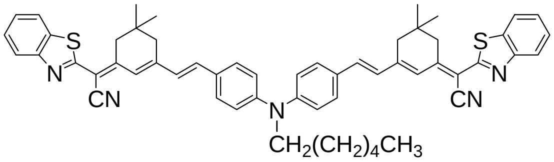


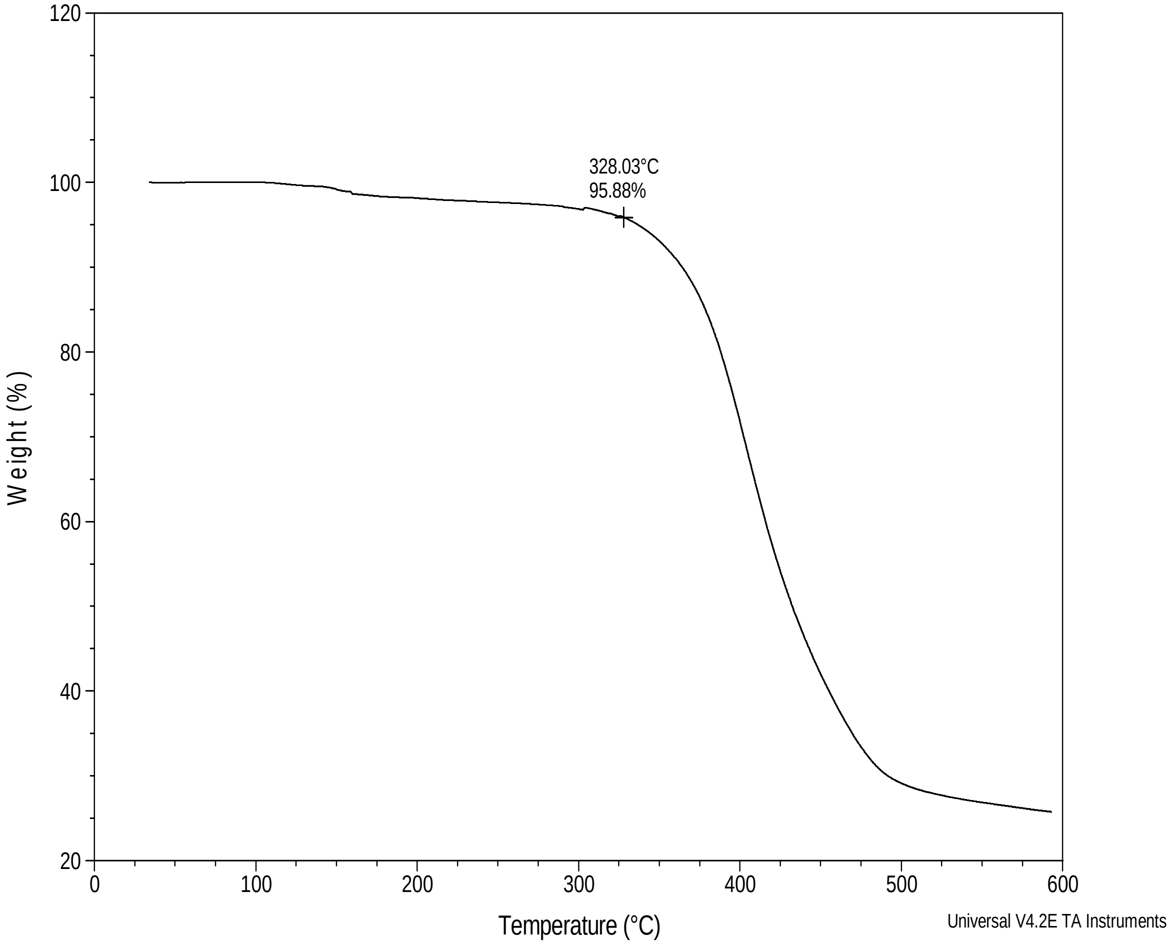
Thermal stability of c



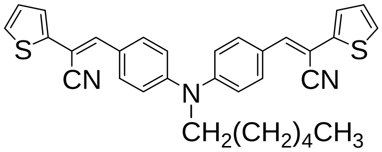


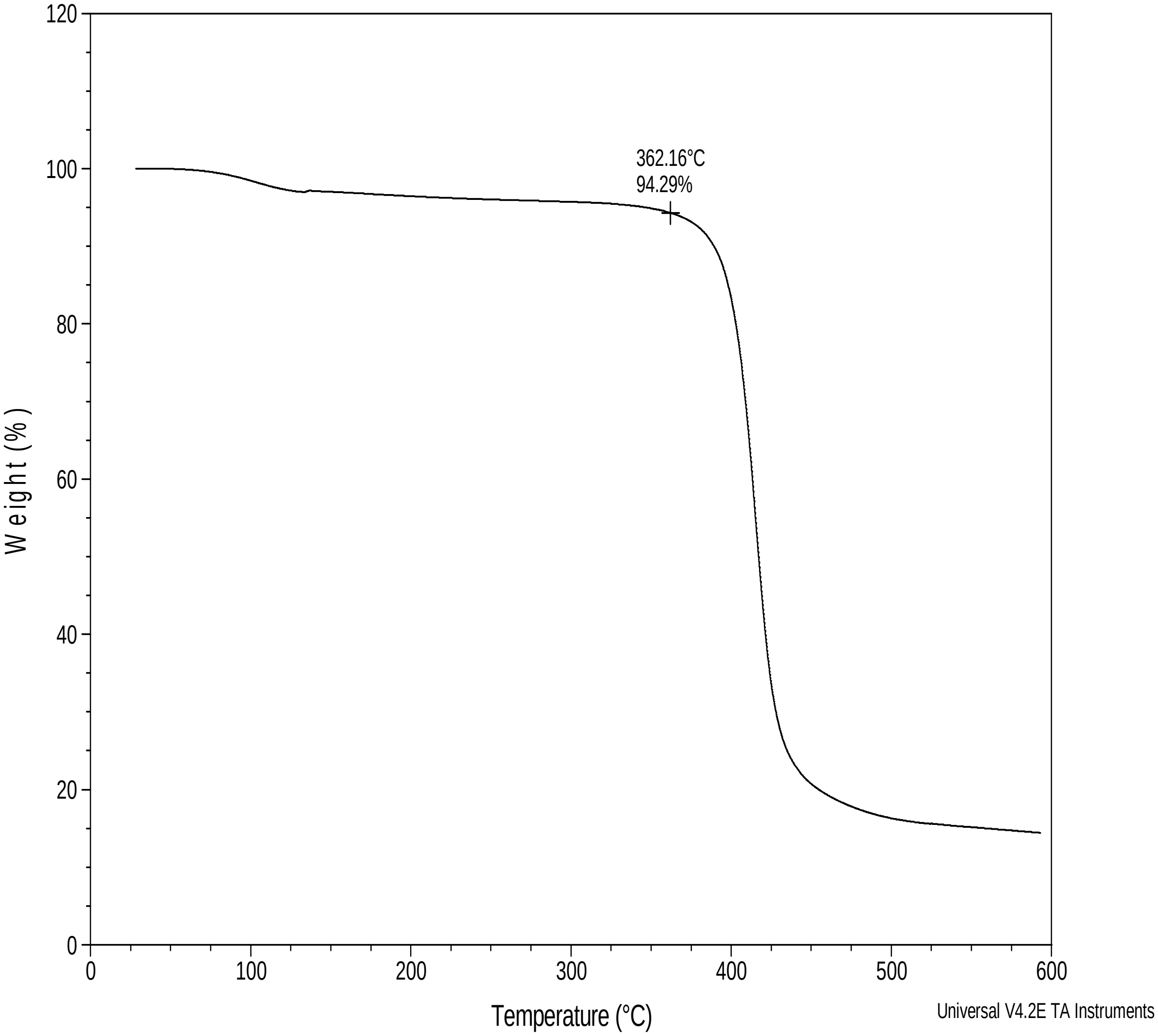
Thermal stability of d



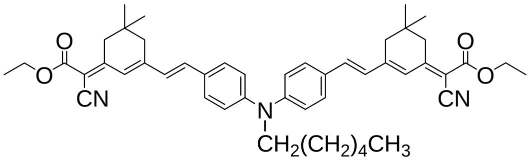


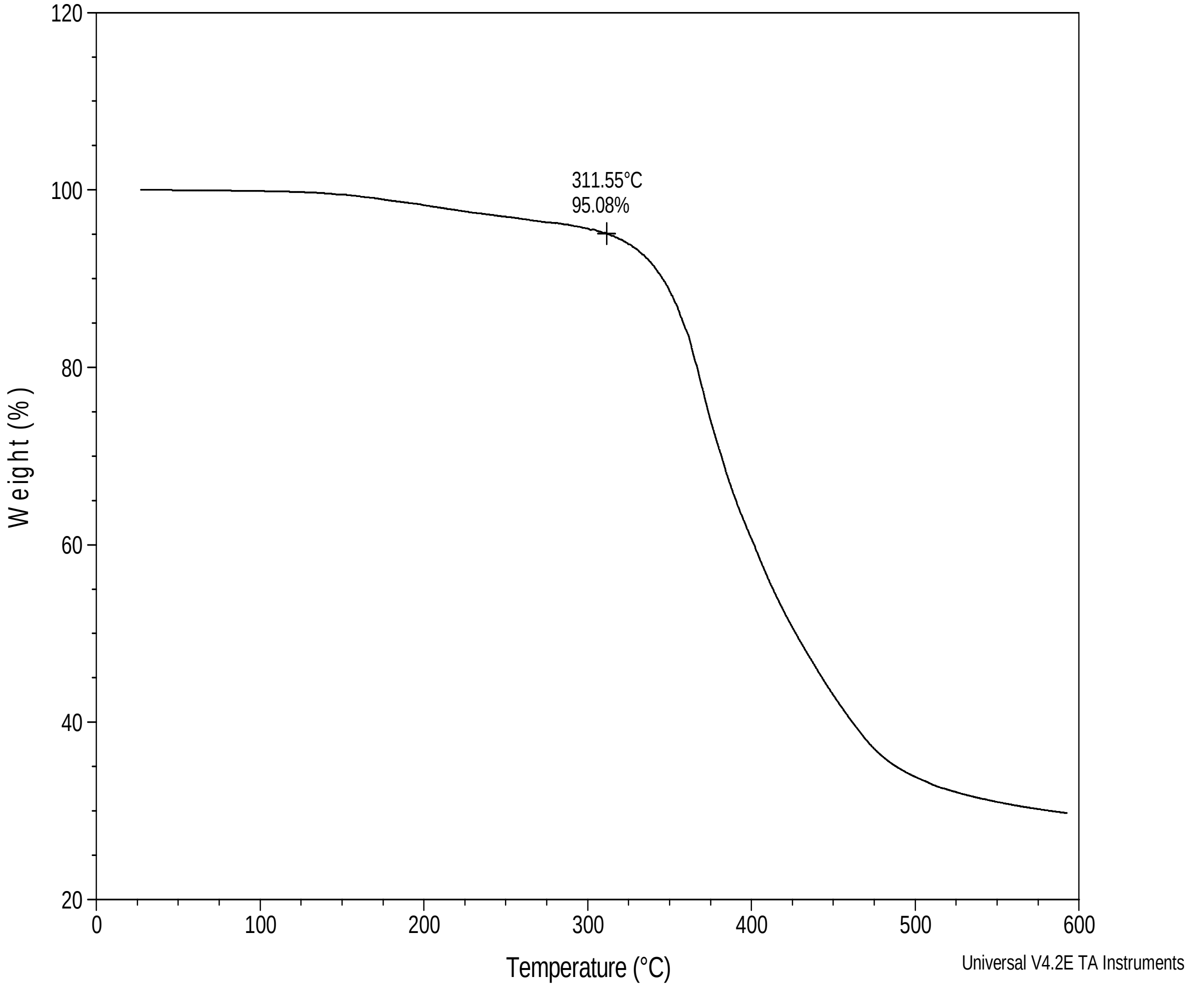
Thermal stability of e



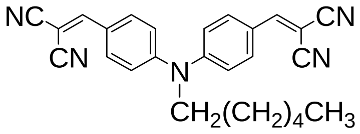


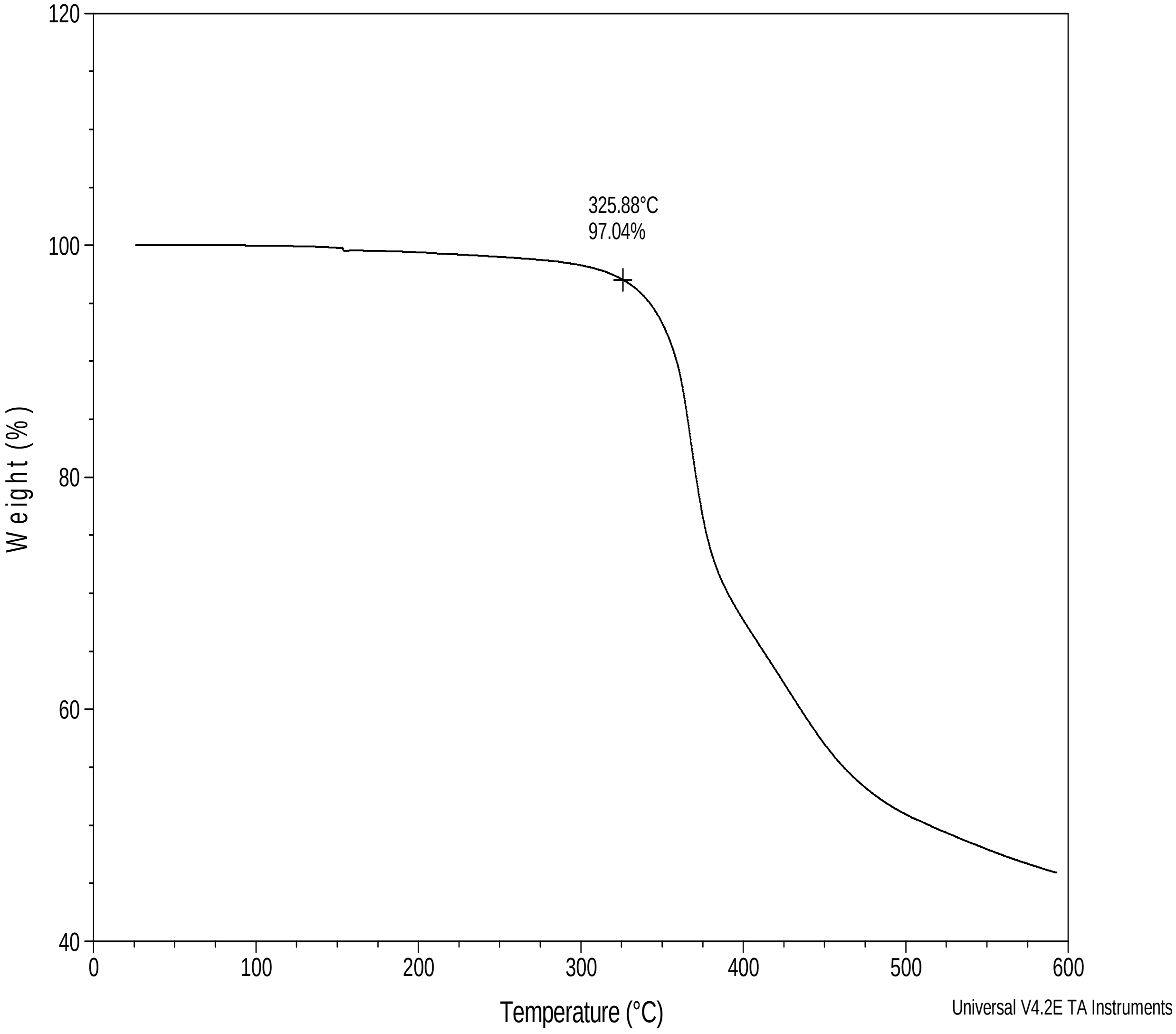
Thermal stability of f



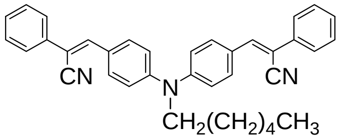


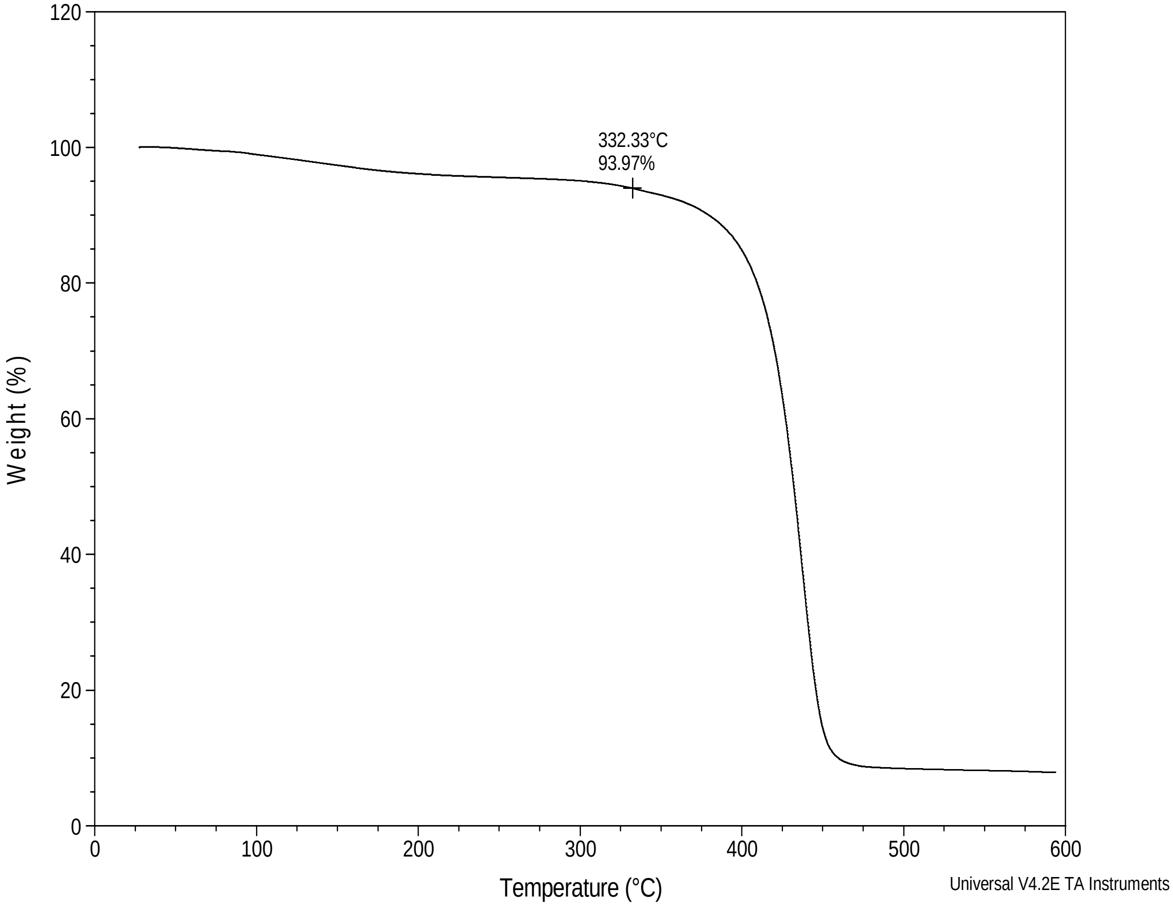
Thermal stability of g



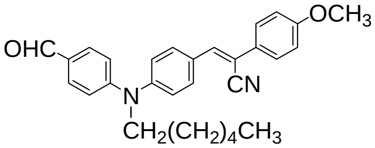


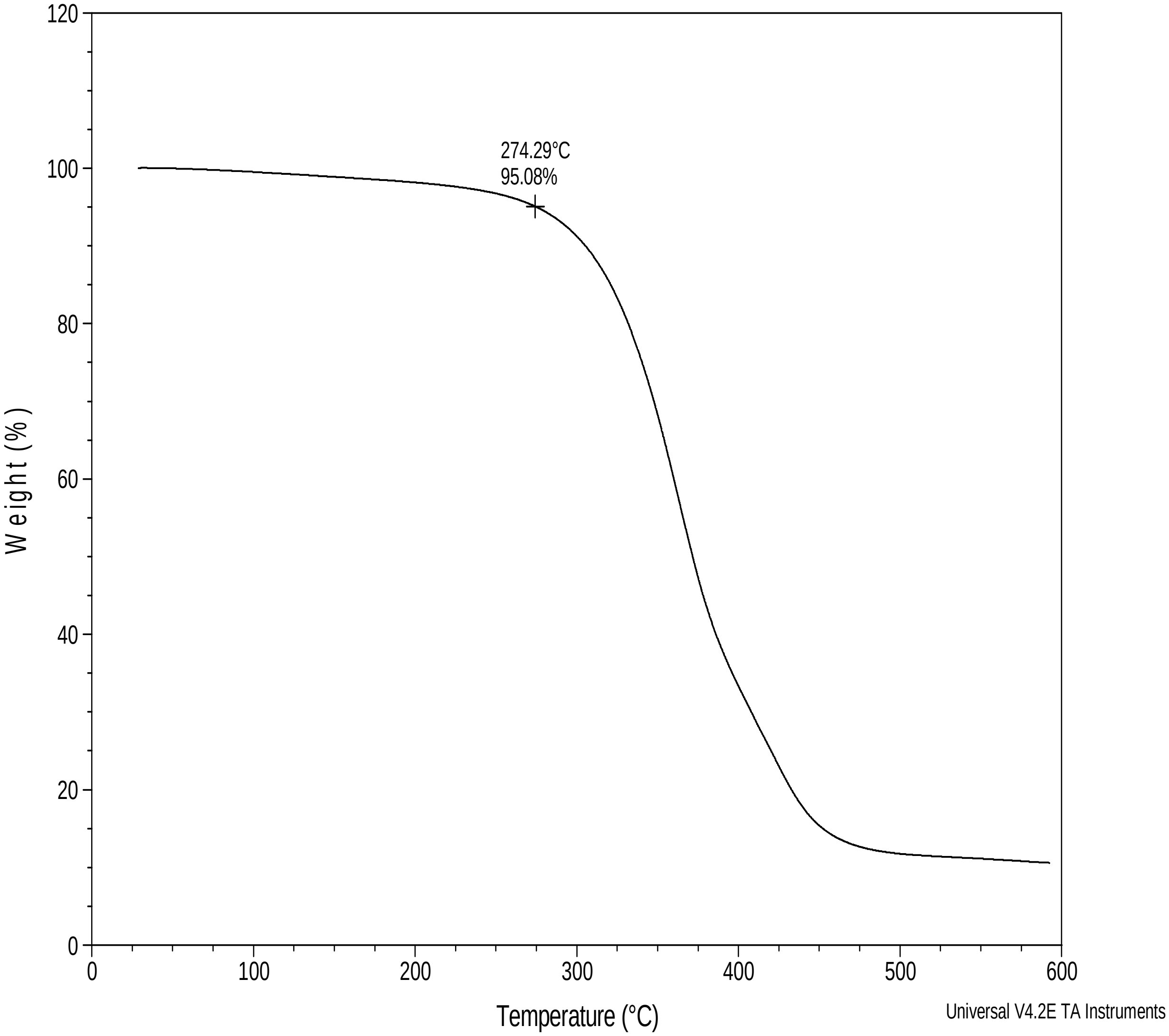
Thermal stability of i





Thermal stability of j





Thermal stability of k