NEW JOURNAL OF CHEMISTRY

Optically Active and Photoswitchable Tröger’s Base Analogs

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Spectroscopic Characterization

1. Characterization of compound (1)

**2,8-Dimethoxy-6H,12H-5,11-methanodibenzo[b,f][1,5]diazocine**

**Exact Mass: 282.14**

![Mass spectrum of compound 1](image)

**Compound 1, MS (ESI +)**

![NMR spectrum of compound 1](image)

**Compound 1, \(^1\)H NMR (400MHz, CDCl\(_3\))**
2. Characterization of compound (2)

2,8-Dimethoxy-6H,12H-5,11-ethanodibenzo[b,f][1,5]diazocine

Exact Mass: 296.15
3. Chiral resolution of compound (2)

**Chiral Discriminator (−)-DBTA, $^1$H NMR (400MHz, CDCl$_3$)**

(±)-2 and (−)-DBTA, Mole ratio 1:1, $^1$H NMR titration (400MHz, CDCl$_3$)
(+)-(R,R)-2 and (−)-DBTA, Mole ratio 1:2, $^1$H NMR titration (400MHz, CDCl$_3$)

(+)-(R,R)-2 and (−)-DBTA, Mole ratio 1:2, $^{13}$C NMR titration (100MHz, CDCl$_3$)
$^1$H NMR titration, Compound 2 in the presence of two mol equivalents of (-)-BDTA

(Stacked view, with a 15% horizontal step, of the peaks corresponding to the indicated CH$_2$ groups in pink)
Chiral HPLC chromatogram, partially resolved 2 (The 1st crop of crystals)

<table>
<thead>
<tr>
<th>Pk #</th>
<th>Retention Time</th>
<th>Area</th>
<th>Area %</th>
</tr>
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<tbody>
<tr>
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<td>12.132</td>
<td>676701</td>
<td>81.05</td>
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<tr>
<td>2</td>
<td>14.116</td>
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<td>18.95</td>
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<tr>
<td>Totals</td>
<td></td>
<td>834953</td>
<td>100.00</td>
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</table>

Chiral HPLC chromatogram, partially resolved 2 (The 2nd crop of crystals)

<table>
<thead>
<tr>
<th>Pk #</th>
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<td>552869</td>
<td>87.46</td>
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<tr>
<td>2</td>
<td>14.084</td>
<td>793026</td>
<td>12.54</td>
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<tr>
<td>Totals</td>
<td></td>
<td>6321715</td>
<td>100.00</td>
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</tbody>
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3: 254 nm, 4 nm Results

<table>
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<th>Pk #</th>
<th>Retention Time</th>
<th>Area</th>
<th>Area %</th>
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<tbody>
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<td>1207847</td>
<td>5.77</td>
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<tr>
<td>2</td>
<td>14.108</td>
<td>19720336</td>
<td>94.23</td>
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Totals |            | 20928183 | 100.00 |

Chiral HPLC chromatogram, partially resolved 2 (The 2nd mother liquor)

3: 254 nm, 4 nm Results

<table>
<thead>
<tr>
<th>Pk #</th>
<th>Retention Time</th>
<th>Area</th>
<th>Area %</th>
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<tr>
<td>2</td>
<td>14.096</td>
<td>4212500</td>
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</table>

Totals |            | 4892650 | 100.00 |

Chiral HPLC chromatogram, partially resolved 2 (The 1st mother liquor)
Chiral HPLC chromatogram, (+)-(R,R)-2 (The 4th recrystallization)

CD spectra, (+)-(R,R)-2 and (−)-(S,S)-2 in DCM
2 in CH$_3$CN (in blue), TCA in CH$_3$CN (0.05%, in green), and 1:1 combination of both (in red)

4. Characterization of compound (3)

6H,12H-5,11-methanodibenzo[b,f][1,5]diazocine-2,8-diol

Exact Mass: 254.11
Compound 3, MS (ESI −)

Exact Mass: 254.11

Compound 3, $^1$H NMR (400 MHz, DMSO-d$_6$)
5. Characterization of compound (4)

6H,12H-5,11-ethanodibenzo[b,f][1,5]diazocine-2,8-diol

Enantiomer Separation

$$\text{(+)-(R,R)-2}$$

$$\text{(-)-(S,S)-2}$$

Demethylation

$$\text{(+)-(R)-4}$$

$$\text{(-)-(S)-4}$$

Mirror image presentation of (+)-4 and (-)-4 enantiomers derived from (+)-2 and (-)-2
Compound 4, MS (ESI –) top and (ESI +) bottom

Exact Mass: 268.12

Compound 4, $^1$H NMR (400 MHz, DMSO-$d_6$)
Compound 4, $^{13}$C NMR (100 MHz, DMSO-$d_6$)

Compound 4, IR transmittance (neat)
6. Characterization of compound (5)

\((E)-3\text{-benzyl-1-(4-butyphenyl)-3-methyltriaz-1-ene}\)

\[
\text{Chemical Formula: } C_{19}H_{13}N_2^+ \\
\text{Exact Mass: } 161.11
\]
Compound 5, $^1$H NMR (400 MHz, CDCl$_3$)

Compound 5, $^{13}$C NMR (100 MHz, CDCl$_3$)
7. Characterization of compound (6)
1,7-bis((E)-(4-methoxyphenyl)diazenyl)-6H,12H-5,11-methanodibenzo[b,f][1,5]diazocine-2,8-diol

Exact Mass: 522.20
Compound 6, $^1$H NMR (400 MHz, CDCl$_3$–CD$_3$OD–(CD$_3$)$_2$CO–(CD$_3$)$_2$SO, 7:1:1:1 v/v) ‡

‡ These combined solvents did dissolve 6 without interfering with the locking and shimming.
8. Characterization of compound (7)

\((E)-1-((4\text{-methoxyphenyl})\text{diazenyl})-6H,12H-5,11\text{-methanodibenzo}[b,f][1,5]\text{diazocine-2,8-diol}\)

**Compound 6, DSC thermogram**
(decomposition without melting at 280–283 °C)

**Compound 7, MS (ESI +) top and (ESI –) bottom**

**Exact Mass: 388.15**

*MSD2 SPC, timer:0.180 of H:Data7-7 MMR 2016-07-07 16-08-06013-P1-AP-104min.D ES-API, Neg, Scan, Pref. 100, *Neg*"
$^1$H NMR 400 MHz of Compound 7 in DMSO-$d_6$ (in blue) and in D$_2$O–DMSO-$d_6$ (in red)

Compound 7, $^1$H NMR (400 MHz, DMSO-$d_6$ – EtOAc)
Compound 7, $^1$H NMR (400 MHz, D$_2$O – DMSO-$_d_6$ – EtOAc)

Compound 7, $^{13}$C NMR (100 MHz, DMSO-$_d_6$ – EtOAc)
Compound 7, HSQC (400 MHz, DMSO-\textit{d}_6 – EtOAc)
Compound 7, HMBC (400 MHz, DMSO-$d_6$ – EtOAc)

Compound 7, IR transmittance (neat)
9. Characterization of compound (8)

1,7-Bis((E)-(4-butylphenyl)diazenyl)-6H,12H-5,11-methanodibeno[b,f][1,5]diazocine-2,8-diol
Compound 8, $^1$H NMR (400 MHz, CDCl$_3$)

Compound 8, $^{13}$C NMR (100 MHz, CDCl$_3$)
Compound 8, COSY (400 MHz, CDCl$_3$)
Compound 8, HSQC (400 MHz, CDCl$_3$)
Compound 8, HMBC (400 MHz, CDCl₃)

Compound 8, HMBC (400 MHz, CDCl₃)
Compound 8, IR transmittance (neat)

10. Characterization of compound (9)
1,7-bis((E)-(4-butylphenyl)diazenyl)-6H,12H-5,11-ethanodibenzo[b,f][1,5]diazocine-2,8-diol

Exact Mass: 588.32
Compound 9, $^1$H NMR (400 MHz, CDCl$_3$, DCM as an internal standard)

Compound 9, $^{13}$C NMR (100 MHz, CDCl$_3$)
Compound 9, COSY (400 MHz, CDCl$_3$)

Compound 9, HSQC (400 MHz, CDCl$_3$)
Compound 9, HMBC (400 MHz, CDCl$_3$)

Compound 9, UV-Vis absorption spectra

$1.6 \times 10^{-5}$ M in EtOAc (Left), and c 0.100 in DCM (Right)
CD spectra, (+)-(R,R)-9 and (−)-(S,S)-9 in DCM

Compound 9, IR transmittance (neat)
11. Characterization of compound (10)
Hexyl (E)-3-((4-(hexyloxy)phenyl)diazenyl)benzoate
Compound 10, $^1$H NMR (400 MHz, CDCl$_3$)

Compound 10, $^{13}$C NMR (100 MHz, CDCl$_3$)
UV-Vis absorption spectra of 10 (260–560nm) and its absorption at 350nm at various stages of the photoisomerization – thermal relaxation

Compound 10, IR transmittance (neat)
12. Characterization of compound (11)

(E)-3-((4-hexyloxy)phenyl)diazenyl)benzoic acid

Exact Mass: 326.16
Compound 11, $^1$H NMR (600 MHz, CDCl$_3$)

Compound 11, $^{13}$C NMR (150 MHz, CDCl$_3$)
13. Characterization of compound (12)

\((E)-3-((4-\text{Hexyloxy})\text{phenyl})\text{diazenyl})\text{benzoyl chloride}\n
**Exact Mass:** 344.13

**Exact Mass:** 368.21

**Compound 12, MS (ESI +):** 

\([M + H]^+\) and \([M + \text{iPrOH} - \text{Cl}]^+\)

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**Compound 12, IR transmittance (neat)**

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Table 1. IR transmittance summary, Compounds 10–12

<table>
<thead>
<tr>
<th>Compound</th>
<th>Functional group; IR peak (cm⁻¹)†</th>
<th>Functional group; IR peak (cm⁻¹)†</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Ester; 1705</td>
<td>Hexyl; 2952</td>
</tr>
<tr>
<td>11</td>
<td>Carboxylic acid; 1694</td>
<td>Hydroxyl; 3060–3350</td>
</tr>
<tr>
<td>12</td>
<td>Acid chloride; 1742</td>
<td>Chloride; 673</td>
</tr>
</tbody>
</table>

†The results are in agreement with the literature¹
14. Characterization of compound (13)
8-hydroxy-6H,12H-5,11-ethanodibenzo[bf][1,5]diazocin-2-yl(E)-3-(4-(hexyloxy)phenyl)diazenyl) benzoate

Exact Mass: 576.27

Compound 13, MS (ESI +)
Compound 1, \(^1\)H NMR (400 MHz, CDCl\(_3\))

Compound 13, \(^1\)H NMR (400 MHz, CDCl\(_3\))

Compound 13, \(^{13}\)C NMR (100 MHz, CDCl\(_3\))
Compound 13, COSY (400 MHz, CDCl₃)

Exact Mass: 576.27

Compound 13, HSQC (400 MHz, CDCl₃)
Compound 13, HMBC (400 MHz, CDCl₃)

Compound 13, IR transmittance (neat)
Compound 13, UV-Vis absorption spectra at different stages of photoisomerization

15. Characterization of compound (14)
6H,12H-5,11-ethanodibenzo[b,f][1,5]diazo
ger-2,8-diyl bis 3-((E)-(4-(hexyloxy)phenyl)diazenyl)benzoate
Compound 14, $^1$H NMR (600 MHz, CDCl$_3$)

Compound 14, $^{13}$C NMR (150 MHz, CDCl$_3$)
Compound 14, IR transmittance (neat)

Compound 14, UV-Vis absorption spectra of 14 at different stages of photoisomerization
CD spectra, (+)-(R,R)-14 and (−)-(S,S)-14 in DCM

16. Characterization of compound (15)

(E)-4-{(4-(hexyloxy)phenyl)diazeny}lbenzoic acid

Exact Mass: 326.16

Compound 15, MS (ESI ±)
Compound 15, $^1$H NMR (400 MHz, DMSO-d$_6$)

Compound 15, $^{13}$C NMR (100 MHz, DMSO-d$_6$)
17. Characterization of compound (16)

*(E)*-4-((4-(hexyloxy)phenyl)diazeny)benzoyl chloride

**Compound 16, MS (ESI +) in MeOH**

**Compound 16, $^1$H NMR (400 MHz, DMSO-$d_6$)**
Compound 16, $^{13}$C NMR (100 MHz, DMSO-$d_6$)

18. Characterization of compound (17)

$6H,12H$-$5,11$-ethanodibenzo[$b,f]$[1,5]diazocine-$2,8$-diyl bis(4-($E$)-4-(hexyloxy)phenyl)diazeneyl) benzoate

Exact Mass: 884.43
Compound 17, MS (ESI +)

Compound 17, $^1$H NMR (400 MHz, CDCl$_3$)
Compound 17, $^{13}$C NMR (100 MHz, CDCl$_3$)

Compound 17, IR transmittance (neat)
CD spectra, (+)-(R,R)-17 and (−)-(S,S)-17 in DCM

Compound 17, UV-Vis absorption spectra at different stages of the photoisomerization
19. Characterization of compound (18)

*(E*)-4-((4-butylphenyl)diazene)-2,6-dimethylphenol

![Molecular structure of compound (18)](image)

Exact Mass: 282.17
Compound 18, $^1$H NMR (400 MHz, CDCl$_3$)

Compound 18, $^{13}$C NMR (100 MHz, CDCl$_3$)
Compound 18, IR transmittance (neat)

Compound 18, IR transmittance before (in blue) and after alkylation (in red)
20. Characterization of compound (19)

\((\text{E})-1-(4-(2\text{-bromoethoxy})-3,5\text{-dimethylphenyl})-2-(4\text{-butylphenyl})diazene\)

![Chemical structure of compound 19](image)

Exact Mass: 388.12
Compound 19, $^1$H NMR (400 MHz, CDCl$_3$)

Compound 19, $^{13}$C NMR (100 MHz, CDCl$_3$)
Compound 19, IR transmittance (neat)

Compound 19, UV-Vis absorption spectra at different stages of photoisomerization
21. Characterization of compound (20)

2,8-bis(2-(4-((E)-(4-butylphenyl)diazenyl)-2,6-dimethylphenoxy)ethoxy)-6H,12H-5,11-ethanodibenzo[b,f][1,5]diazocine

Exact Mass: 884.50
Compound 20, $^1$H NMR (400 MHz, CDCl$_3$)

Compound 20, $^{13}$C NMR (100 MHz, CDCl$_3$)
Compound 20, UV-Vis absorption spectra at different stages of photoisomerization

CD spectra, (+)-(R,R)-20 and (−)-(S,S)-20 in DCM
22. Characterization of compound (21)

(E)-4-((4-octyloxy)naphthalen-1-yl)diazenyl)benzoic acid

Exact Mass: 292.08
Crude 21 (after octylation), MS (ESI +)

Exact Mass: 516.34

Compound 21 (after hydrolysis), MS (ESI +)

Exact Mass: 404.21
Compound 21, $^1$H NMR (600 MHz, DMSO-$d_6$)

Compound 21, $^{13}$C NMR (150 MHz, DMSO-$d_6$)
23. Characterization of compound (22)

6H,12H-5,11-ethanodibenzo[b,f][1,5]diazocine-2,8-diyl bis(4-{(E)-(4-octyloxy)naphthalen-1-yl)diazenyl)benzoate)

Exact Mass: 1040.52
Exact Mass: 1040.52

Compound 22, $^1$H NMR (600 MHz, CDCl$_3$)

Compound 22, $^1$H NMR (600 MHz, CDCl$_3$)
Compound 22, $^{13}$C NMR (150 MHz, CDCl$_3$)

**Compound 22, UV-Vis absorption spectra at different stages of photoisomerization**
CD spectra, \((+)-(R,R)-22 \text{ and } (-)-(S,S)-22\) in DCM

Compound 22, IR transmittance (neat)
### Chiral Cores

Table 2. Comparing the optical activity of TBAs to other types of chiral centers employed in the design of photoresponsive chiral compounds

<table>
<thead>
<tr>
<th>Compound name</th>
<th>Chemical structure</th>
<th>$[\alpha]_D^{211.4\text{C}} \pm 1^\circ$</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(R)-(−)-2-Octanol</td>
<td><img src="image1" alt="Chemical structure" /></td>
<td>$-9.5^\circ$ (neat)</td>
<td>2</td>
</tr>
<tr>
<td>Dianhydro-D-glucitol</td>
<td><img src="image2" alt="Chemical structure" /></td>
<td>$+45^\circ$ (C = 3, H$_2$O)</td>
<td>2a, 3</td>
</tr>
<tr>
<td>(S)-(+)2-Octanol</td>
<td><img src="image3" alt="Chemical structure" /></td>
<td>$+9.5^\circ$ (neat)</td>
<td>2</td>
</tr>
<tr>
<td>(R)-(−)-1,1′-Binaphthyl-2,2′-diamine</td>
<td><img src="image4" alt="Chemical structure" /></td>
<td>$+157^\circ$ (C=1, Py)</td>
<td>2a, 4</td>
</tr>
<tr>
<td>(5S,11S)-2,8-Dimethyl-6H,12H-5,11-methanodibenzob[6,f][1,5] diazocine</td>
<td><img src="image5" alt="Chemical structure" /></td>
<td>$+282^\circ$ (C=0.11, CHCl$_3$)</td>
<td>5</td>
</tr>
<tr>
<td>(5S,11S)-2,8-Dimethoxy-6H,12H-5,11-methanodibenzob[6,f][1,5] diazocine</td>
<td><img src="image6" alt="Chemical structure" /></td>
<td>$+236^\circ$ (C=0.11, CHCl$_3$)</td>
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<tr>
<td>(5S,11S)-2,8-Dibromo-6H,12H-5,11-methanodibenzob[6,f][1,5] diazocine</td>
<td><img src="image7" alt="Chemical structure" /></td>
<td>$+379^\circ$ (C=0.11, CHCl$_3$)</td>
<td>5</td>
</tr>
<tr>
<td>(−)-(5S,11S)-2,8-dimethoxy-6H,12H-5,11-ethanodibenzob[6,f][1,5] diazocine</td>
<td><img src="image8" alt="Chemical structure" /></td>
<td>$−332^\circ$ (C=0.10, DCM)</td>
<td>This work</td>
</tr>
<tr>
<td>(+)-(5R,11R)-2,8-dimethoxy-6H,12H-5,11-ethanodibenzob[6,f][1,5] diazocine</td>
<td><img src="image9" alt="Chemical structure" /></td>
<td>$+337^\circ$ (C=0.10, DCM)</td>
<td>This work</td>
</tr>
</tbody>
</table>
Acid-Resistant Chirality

Elaboration on the acid-resistant chirality of the modified Tröger’s base analogues
Photographs of Planar Cell

Observing an image reflected off a planar cell filled with (+)-(R,R)-9 doped 7CB (3.2 mol%) through the left filter of a passive 3D glasses

Observing an image reflected off a planar cell filled with (+)-(R,R)-9 doped 7CB (3.2 mol%) through the right filter of a passive 3D glasses
The planar cell placed between a pair of crossed (A) and parallel (B) linear polarizers

Phase Transition Observation

Phase transition and thermochromism of (+)-(R,R)-9 doped 7CB (3.2 mol%)
**Experimental**

**General Experimental Methods.** NMR spectra were recorded at 298 K using Bruker DRX400 and Cryoplatform600 MHz instruments, and Topspin V. 3.2 software. IR transmittance spectra were recorded at rt using Thermo Scientific Nicolet iS5/ATR10. HPLC chromatograms were recorded at 254 nm (optical detection) using Shimadzu CTO-20A instrument equipped with Phenomenex chiral analytical column (Lux-amyllose-1, 250x4.6mm, 5 µm). Gravity-column chromatography was performed at rt using Davisil silica gel (LC60Å, 40–63µm) or Sigma-Aldrich alumina (neutral, 60–325 mesh) as stationary phases. Merck DC-Kieselgel60–F254 aluminium plates were used for analytical TLC. Solvent systems reported with Rf values were used for both TLC and column chromatography. Fluorescence analysis cabinet (CM-10) fitted with Spectroline UV lamps ENF-260C/ATR10 was employed for TLC screening and illumination experiments. LC/ESI-MS was performed by Agilent-6130 Quadrupole using CH3CN as mobile phase modified with formic acid (0.05 %) or ammonium formate (0.10 %) for positive and negative scans, respectively. Elemental analysis performed by Vario EL-Elementar and PerkinElmer-2400-SII analyzers. UV-Vis spectra were recorded at rt using Varian (Cary-1) or Eppendorf (Kinetic-Bio) spectrophotometers. PerkinElmer P-1010 polarimeter recorded optical rotations; c and [α] are reported in g/100mL and (deg.mL)/(g.dm), respectively. Jasco J-810 spectropolarimeter recorded CD spectra.

**Synthesis Procedures and Analytical Data**

**COMPOUND 1**

2,8-Dimethoxy-6H,12H-5,11-methanodibenzo[b,f][1,5]diazocine (1).

Synthesized and purified according to the literature. 6 Rf 0.22 (silica gel; iPrOH – nHex, 10% v/v). 1H NMR (400 MHz, CDCl3): δ 7.06 (d, J = 8.8 Hz, 2H), 6.75 (dd, J = 8.8, 2.8 Hz, 2H), 6.43 (d, J = 2.8 Hz, 2H), 4.65 (d, J = 16.5 Hz, 2H), 4.30 (s, 2H), 4.08 (d, J = 16.5 Hz, 2H), 3.71 (s, 6H), 3.67 (s, 6H), 3.54–3.59 (m, 4H). MS (ESI +, Quadrupole): m/z [M + H]+ calcd for [C17H19N2O2]+: 283.14; found: 283.1. Mp: 164–165°C (lit.7 163–165°C).

**COMPOUND 2**

2,8-Dimethoxy-6H,12H-5,11-ethanodibenzo[b,f][1,5]diazocine (2).

Synthesized and purified according to the literature. 8 Jameson’s procedure 5 with slight changes, enabled the chiral resolution of 2 through its co-precipitation with enantiopure O, O′-dibenzoyltartaric acid (Mole ratio of 1:3 respectively), using dry CH3CN instead of DCE, and recrystallizing the precipitated complex in fresh CH3CN for four times before the final work-up. Rf 0.30 (silica gel; iPrOH – nHex, 10% v/v). 1H NMR (400 MHz, CDCl3): δ 7.06 (d, J = 8.6 Hz, 2H), 6.62 (dd, J = 8.6, 2.8 Hz, 2H), 6.43 (d, J = 2.8 Hz, 2H), 4.54 (d, J = 17.3 Hz, 2H), 4.37 (d, J = 17.3 Hz, 2H), 3.71 (s, 6H), 3.54–3.59 (m, 4H). MS (ESI +, Quadrupole): m/z [M + H]+ calcd for [C18H21N2O2]+: 297.15; found: 297.1. Enantiomer (+)-(R,R)-2: [α]D22 +337 (c 0.100, DCM), Chiral HPLC tR 12.1 ± 0.2 min (major >99.8%, er >99.5:0.5); Enantiomer (−)-(S,S)-2: [α]D23 −332 (c 0.100, DCM), Chiral HPLC tR 14.1 ± 0.2 min (major >99.8%, er >99.5:0.5). Mp: 186–187°C (lit.8 186–189°C).
COMPOUND 3

6H,12H-5,11-Methanodibenzo[b,f][1,5]diazocine-2,8-diol (3).

Compound 1 converted to 3 according to the literature.\textsuperscript{9} R\textsubscript{i} 0.4 (silica gel; EtOAc). \textsuperscript{1}H NMR (400 MHz, DMSO-\textit{d}_6): \(\delta\) 9.00 (s, 2H), 6.89 (d, \(J = 8.7\) Hz, 2H), 6.55 (dd, \(J = 8.7, 2.7\) Hz, 2H), 6.31 (d, \(J = 2.7\) Hz, 2H), 4.46 (d, \(J = 16.7\) Hz, 2H), 4.12 (s, 2H), 3.89 (d, \(J = 16.6\) Hz, 2H). MS (ESI+, Quadrupole): \(m/z\ [M + H]^+\) \textit{calcld} for \([\text{C}_{15}\text{H}_{13}\text{N}_2\text{O}_2]^+: \) 255.11; found: 255.1. MS (ESI−, Quadrupole): \(m/z\ [M − H]^−\) \textit{calcld} for \([\text{C}_{15}\text{H}_{13}\text{N}_2\text{O}_2]^−: 253.11; found: 253.1. Mp: 128–130°C.

COMPOUND 4

6H,12H-5,11-Ethanodibenzo[b,f][1,5]diazocine-2,8-diol (4).

An enantiomer of 2 (1.0 g, 3.3 mmol) in dry DCM (20 mL) cooled down to −78°C under argon atmosphere, then neat BBr\textsubscript{3} (8.2 g, 33 mmol, excess) was cautiously added by addition funnel. The suspension was stirred (48 h, rt), poured into crushed ice (200 g), thoroughly mixed, and its pH was adjusted to 5 by adding NaOH (4.0 g) and AcOH (2 mL). The resulting solution was extracted with EtOAc (5×50 mL) and discarded. The collected organic layers were combined, dried over \(\text{Na}_2\text{SO}_4\) and filtered. The solvent was removed under reduced pressure to obtain product 4 as a white powder. Yield: 0.86 g (3.2 mmol, 97%); \(R\textsubscript{i} 0.5\) (silica gel; EtOAc). \textsuperscript{1}H NMR (400 MHz, DMSO-\textit{d}_6): \(\delta\) 8.93 (s, 2H), 6.83 (d, \(J = 8.4\) Hz, 2H), 6.40 (dd, \(J = 8.4, 2.7\) Hz, 2H), 6.26 (d, \(J = 2.7\) Hz, 2H), 4.41 (d, \(J = 17.2\) Hz, 2H), 4.13 (d, \(J = 17.2\) Hz, 2H), 3.37 (s, 4H). \textsuperscript{13}C\textsuperscript{(H)} NMR (100 MHz, DMSO-\textit{d}_6): \(\delta\) 153.9, 141.6, 138.2, 128.4, 114.3, 113.6, 58.6, 54.6. MS (ESI+, Quadrupole): \(m/z\ [M + H]^+\) \textit{calcld} for \([\text{C}_{16}\text{H}_{11}\text{N}_2\text{O}_2]^+: 269.12; found: 269.1. MS (ESI−, Quadrupole): \(m/z\ [M − H]^−\) \textit{calcld} for \([\text{C}_{16}\text{H}_{11}\text{N}_2\text{O}_2]^−: 267.12; found: 267.2. IR (neat): 3027, 2954, 2926, 2856, 1495, 1446, 1342, 1171, 1054 cm\textsuperscript{−1}. UV-Vis: (EtOAc) \(\lambda\) (lg\(\varepsilon\)) = 289 nm (3.868). Mp: 282–283°C. Anal. Calcd for \(\text{C}_{16}\text{H}_{12}\text{N}_2\text{O}_2\): C, 71.62; H, 6.01; N, 10.44. Found: C, 71.51; H, 6.28; N, 10.35. Enantiomer \((-\)-(R,R)-4: [\alpha]_D^{22}+261 (c 0.100, EtOAc) obtained from \((-\)-(R,R)-2; Enantiomer \((-\)-(S,S)-4: [\alpha]_D^{24}−232 (c 0.100, EtOAc) obtained from \((-\)-(S,S)-2.

COMPOUND 5

(E)-3-Benzyl-1-(4-butylphenyl)-3-methyltriaz-1-ene (5).

Water (50 mL), \(\text{H}_2\text{SO}_4\) (98%, 4 mL), 4-n-butylaniline (1.2 g, 8.0 mmol), and \(\text{CH}_3\text{CN}\) (30 mL) respectively poured into a round bottom flask and mixed together until homogeneous. The solution was cooled to −5°C, added \(\text{NaNO}_2\) (0.69 g, 10 mmol, excess, in cold water 5 mL), and stirred (40 min, −5°C). The resulting clear solution was added to a cooled mixture of \(n\)-benzylmethylamine (3.0 mL, excess), \(\text{Na}_2\text{CO}_3\) (9.0 g), water (50 mL), and \(\text{CH}_3\text{CN}\) (30 mL) and stirred (3 h, −5°C). The reaction mixture was diluted with cold water (200 mL) to precipitate out a beige waxy lump that was then extracted with DCM (2×50 mL). The DCM layers were combined, dried over \(\text{Na}_2\text{SO}_4\) filtered, and evaporated to dryness. The crude was chromatographed to obtain 5 as a slightly yellow oil that was then stored at −20°C. Yield: 2.12 g (7.54 mmol, 94%); \(R\textsubscript{i} 0.6\) (silica gel; EtOAc–nHex, 10% v/v). \textsuperscript{1}H NMR (400 MHz, CDCl\textsubscript{3}): \(\delta\) 7.31 (d, \(J = 8.3\) Hz, 2H), 7.11–7.21 (m, 5H), 7.05 (d, \(J = 8.3\) Hz, 2H), 4.78 (s, 2H), 3.00 (s, 3H), 2.49 (t, 2H, \(J = 7.8\) Hz), 1.45–1.53 (m, 2H), 1.20–1.29 (m, 2H), 0.82 (t, \(J = 7.5\) Hz, 3H). \textsuperscript{13}C\textsuperscript{(H)} NMR (100 MHz, CDCl\textsubscript{3}): \(\delta\) 148.8, 140.4, 137.0, 128.9, 128.7, 127.9, 127.7, 120.6, 68.5, 58.8, 35.3, 33.8, 22.4, 14.1. MS (ESI+, Quadrupole): \(m/z\) calcd for \([\text{C}_{16}\text{H}_{13}\text{N}_2]^+: 161.11; found: 161.1; \(m/z\) calcd for \([\text{C}_{16}\text{H}_{12}\text{N}]^+: 122.10; found: 122.2. Anal. NA (unstable oil). IR (neat): 3027, 2954, 2926, 2856, 1495, 1446, 1342, 1171, 1054, 833, 729 cm\textsuperscript{−1}. UV-Vis: (EtOAc) \(\lambda\) (lg\(\varepsilon\)) = 313 nm (3.462).

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COMPOUND 6
1,7-Bis[(E)-(4-methoxyphenyl)diazhenyl]-6H,12H-5,11-methanodibenzo[b,f][1,5]diazocine-2,8-diol (6). 4-Anisidine (0.54 g, 4.4 mmol) in dilute H$_2$SO$_4$ (6.5%, 30 mL) cooled down to −5°C. NaNO$_2$ (0.30 g, 4.4 mmol, in cold water 5 mL) was dropped into the solution and stirred (30 min, −5°C). The resulting yellowish solution was added to a fresh solution of 3 (0.51 g, 2.0 mmol) and Na$_2$CO$_3$ (4.0 g) in ice-cold water (100 mL) and stirred for 18 h. A brown precipitate was filtered off, washed thoroughly with distilled water, and desiccated to obtain the crude that was then chromatographed to obtain 6 as the minor product. Yield: 0.13 g (0.25 mmol, 12%); $R_f$ 0.55 (silica gel; MeOH–DCM, 4% v/v). $^1$H NMR (400 MHz, CDCl$_3$–CD$_3$OD–(CD$_3$)$_2$CO–DMSO–d$_6$, 7:1:1:1 v/v): δ 13.04 (s, 2H Exchangeable, OH), 7.63 (d, $J = 9.1$ Hz, 4H, CH), 7.06 (d, $J = 8.9$ Hz, 2H, CH), 6.85 (d, $J = 9.1$ Hz, 4H, CH), 6.68 (d, $J = 8.9$ Hz, 2H, CH), 4.78 (d, $J = 17.7$ Hz, 2H, CH$_2$), 4.66(d, $J = 17.7$ Hz, 2H, CH$_2$), 4.24 (s, 2H, NCH$_2$N), 3.73 (s, 6H, OCH$_3$). $^{13}$C$^{(1)}$H NMR (100 MHz, CDCl$_3$–CD$_3$OD–(CD$_3$)$_2$CO–DMSO–d$_6$, 7:1:1:1 v/v): δ 162.1, 148.9, 144.7, 139.7, 132.9, 130.0, 128.2, 123.8, 117.3, 114.4, 66.2, 55.7, 55.4. MS (ESI +, Quadrupole): $m/z$ [M + H]$^+$ calcd for [C$_{26}$H$_{27}$N$_3$O$_4$]$: 523.21, found 523.2; (ESI −, Quadrupole) calcd for [C$_{26}$H$_{25}$N$_3$O$_4$]$^-$: M − H$^-$ 521.19, found 521.1. IR (neat): 3452, 3018, 2942, 1757, 1433, 1424, 1151, 1037 and 869 cm$^{-1}$. Dec. range: 280–283 °C (determined by DSC). UV-Vis: (EtOAc) λ (lge) = 368 nm (4.482). Anal. Calcd for C$_{26}$H$_{27}$N$_3$O$_4$: C, 66.66; H, 5.02; N, 16.08. Found: C, 66.42; H, 5.21; N, 15.95.

COMPOUND 7
(E)-1-((4-Methoxyphenyl)diazhenyl)-6H,12H-5,11-methanodibenzo[b,f][1,5]diazocine-2,8-diol (7). Obtained as the major product of the previous reaction that described the synthesis of 6. This asymmetrical product precipitated out of the reaction mixture due to its poor solubility, and hence was not well exposed to the diazonium salt and became the major product. Yield: 0.48 g (1.23 mmol, 62%); $R_f$ 0.45 (silica gel; EtOAc–DCM, 50% v/v). $^1$H NMR (400 MHz, DMSO–d$_6$ – EtOAc): δ 12.68 (s, 1H, OH), 9.04 (s, 1H, OH), 7.85 (d, $J = 8.8$ Hz, 2H, CH), 7.18 (d, $J = 8.8$ Hz, 1H, CH), 7.08 (d, $J = 9.2$ Hz, 2H, CH), 6.99 (d, $J = 8.7$ Hz, 1H, CH), 6.82 (d, $J = 8.9$ Hz, 1H, CH), 6.56 (dd, $J = 8.6$, 2.6 Hz, 1H, CH), 6.35 (d, $J = 2.5$ Hz, 1H, CH), 4.51–4.82 (m, 3H, CH$_2$), 4.22 (s, 2H, NCH$_2$N), 4.03 (m, 1H, CH$_2$), 3.84 (s, 3H, OCH$_3$). $^{13}$C$^{(1)}$H NMR (100 MHz, DMSO–d$_6$ – EtOAc): δ 162.0, 153.4, 148.1, 144.5, 140.5, 139.4, 132.7, 130.3, 128.6, 128.5, 125.7, 124.1, 116.7, 114.8, 114.5, 112.3, 66.2, 57.7, 56.1, 55.6. MS (ESI +, Quadrupole): $m/z$ [M + H]$^+$ calcd for [C$_{22}$H$_{19}$N$_3$O$_2$]$: 389.15, found 389.2; (ESI −, Quadrupole) calcd for [C$_{22}$H$_{19}$N$_3$O$_2$]$^-$: [M − H]$^-$ 387.15, found 387.1. IR (neat): 3433, 3029, 2935, 2888, 2839, 1593, 1500, 1482, 1440, 1250, 1142, 1027 and 829 cm$^{-1}$. Dec. range: 267–271 °C (determined by DSC). UV-Vis: (EtOAc) λ (lge) = 367 nm (4.256). Anal. Calcd for C$_{22}$H$_{19}$N$_3$O$_2$: C, 68.03; H, 5.19; N, 14.42. Found: C, 68.27; H, 5.38; N, 14.19.

COMPOUND 8
1,7-Bis[(E)-(4-butylaniline)diazhenyl]-6H,12H-5,11-methanodibenzo[b,f][1,5]diazocine-2,8-diol (8). Distilled water (25 mL) was poured into a 100mL round-bottom flask, then added H$_2$SO$_4$ (98%, 2 mL). A solution of 4-n-butylaniline (1.2 g, 8.0 mmol) in CH$_2$CN (20 mL) was added to the flask while the acid solution was still warm (50–60 °C). The solution cooled down to −5°C, NaNO$_2$ solution (0.69 g, 10 mmol in cold water 5 mL) was added dropwise, and stirred for 35 min. The resulting clear solution was slowly added to a mixture consisting of 3 (0.51 g, 2.0 mmol), Na$_2$CO$_3$ (4.0 g), water (20 mL), and CH$_2$CN (20 mL), and stirred (2h, −5°C). Cold water (50 mL) was added and stirred again (12 h, rt). A few drops of HCl solution (0.1 N) was added to form a brown organic precipitate that was then extracted from the aqueous mixture with DCM (2 × 50 mL). The DCM layers were combined, dried over MgSO$_4$, filtered, and evaporated to dryness. The crude was
chromatographed to obtain 8 as a maroon solid. Yield: 1.1 g (1.9 mmol, 95%); Rf 0.3 (silica gel; EtOAc – nHex, 20% v/v). 1H NMR (400 MHz, CDCl3): δ 13.30 (s, 2H, OH), 7.72 (d, J = 8.5 Hz, 4H, CH), 7.31 (d, J = 8.5 Hz, 4H, CH), 7.29 (d, J = 9.0 Hz, 2H, CH), 6.89 (d, J = 9.0 Hz, 2H, CH), 5.00 (d, J = 17.8 Hz, 2H, CH2), 4.85 (d, J = 17.8 Hz, 2H, CH2), 4.45 (s, 2H, NCH3), 2.68 (t, J = 7.7 Hz, 4H, CH2), 1.60–1.68 (m, 4H, CH2), 1.34–1.43 (m, 4H, CH2), 0.93–0.97 (t, J = 7.4 Hz, 6H, CH3). 13C{1H} NMR (100 MHz, CDCl3): δ 150.3, 148.9, 147.1, 139.6, 133.4, 130.9, 129.5, 128.6, 122.3, 118.0, 66.8, 56.0, 35.7, 33.4, 22.4, 14.0. MS (ESI+, Quadrupole): m/z [M + H]+ calc'd for [C35H39N2O2]+: 575.30, found 575.29. IR (neat): 3062, 2954, 2927, 2856, 1599, 1476, 1424, 1314, 1175, 1081, 902, 831 cm⁻¹. Mp: 160–162°C. UV-Vis: (EtOAc) λ (lge) = 353nm (4.658). Anal. Calc'd for C35H39N2O2: C, 73.14; H, 6.66; N, 14.62. Found: C, 73.26; H, 6.75; N, 14.83.

**COMPOUND 9**

1,7-bis[(E)-(4-butylphenyl)diazienyl]-6H,12H-5,11-ethanodibenzo[b,f][1,5]diazocine-2,8-diol (9). The synthesis procedure of 9 was started with one enantiomer of 4 (0.54 g, 2 mmol) instead of using 3. This resulted in 9 as a maroon solid. Yield: 0.98 g (1.6 mmol, 83%); Rf 0.3 (silica gel; EtOAc – nHex, 15% v/v). 1H NMR (400 MHz, CDCl3): δ 13.30 (s, 2H, OH), 7.74 (d, J = 8.5 Hz, 4H, CH), 7.31 (d, J = 8.5 Hz, 4H, CH), 7.29 (d, J = 8.8 Hz, 2H, CH), 6.80 (d, J = 8.8 Hz, 2H, CH), 5.70 (d, J = 18.5 Hz, 2H, NCH3), 4.77 (d, J = 18.5 Hz, 2H, CH2), 3.70–3.81 (m, 4H, NCH3), 2.67 (t, J = 7.5 Hz, 4H, CH2), 1.63–1.70 (m, 4H, CH2), 1.37–1.46 (m, 4H, CH2), 1.00 (t, J = 7.3 Hz, 6H, CH3). 13C{1H} NMR (100 MHz, CDCl3): δ = 150.8, 148.7, 146.5, 142.8, 137.4, 134.5, 134.3, 129.3, 122.1, 117.1, 55.3, 54.6, 35.5, 33.3, 22.3, 13.9. MS (ESI+, Quadrupole): m/z [M + H]+ calc'd for [C36H37N2O2]+: 589.32, found 589.3. IR (neat): 3028, 2935, 2927, 2855, 1600, 1477, 1316, 1279, 1153, 996, 823 cm⁻¹. Mp: 116–118°C. UV-Vis: (DCM) λ (lge) = 355 nm (4.663). Anal. Calc'd for C36H40N2O2: C, 73.44; H, 6.85; N, 14.27. Found: C, 73.61; H, 6.94; N, 14.09. Enantiomer (+)-(R,R)-9: [α]0.100 +1826 (c 0.100, DCM) obtained from (+)-(R,R)-4; Enantiomer (−)-(S,S)-9: [α]0.29 –1754 (c 0.100, DCM) obtained from (−)-(S,S)-4.

**COMPOUND 10**

Hexyl (E)-3-[(4-hexyloxy)phenyl]diazienyl]benzoate (10). 3-Aminobenzoic acid (2.0 g, 15 mmol) in HCl solution (7.4%, 100 mL) cooled down to −5°C, then NaNO2 (1.1 g, 16 mmol, in ice-cold water 10 mL) was gradually added and the solution stirred for 30 min. The obtained solution was added to a fresh solution of phenol (1.5 g, 16 mmol) and Na2CO3 (2.1 g) in 40 mL of cold water and stirred for 4 h. The solution was acidified with HCl until precipitate out a yellow colour solid. The yellow solid was collected by filtration, rinsed with distilled water and dried under high-vacuum. The crude was added to a mixture of K2CO3 (6.2 g, 45 mmol), 1-hexylbromide (7.4 g, 45 mmol), and KI (0.17 g, 1.0 mmol) in 80 mL of dry acetone, and refluxed for 18 h. The reaction mixture cooled, filtered and reduced under high-vacuum to obtain an orange residue that was then chromatographed to obtain 10 as a shiny orange solid. Yield: 4.5 g (11 mmol, 73%); Rf 0.75 (silica gel; EtOAc – nHex, 10% v/v). 1H NMR (400 MHz, CDCl3): δ 8.55 (s, 1H), 8.13 (d, J = 7.8 Hz, 1H), 8.08 (d, J = 7.8 Hz, 1H), 7.96 (d, J = 8.5 Hz, 2H), 7.59 (t, J = 8.2 Hz, 1H), 7.03 (d, J = 8.5 Hz, 2H), 4.39 (t, J = 7.0 Hz, 2H), 4.06 (t, J = 6.6 Hz, 2H), 1.79–1.88 (m, 4H), 1.45–1.55 (m, 4H), 1.32–1.46 (m, 8H), 0.94 (t, J = 7.3 Hz, 6H). 13C{1H} NMR (100 MHz, CDCl3): δ 166.3, 162.2, 152.8, 146.8, 131.7, 131.1, 129.1, 126.3, 125.1, 124.1, 114.8, 68.5, 65.5, 31.7, 31.6, 29.2, 28.8, 25.8, 22.7, 22.6, 14.1. MS (ESI+, Quadrupole): m/z [M + H]+ calc'd for [C36H35N2O2]+: 411.26, found 411.2. IR (neat): 2925, 2917, 2853, 1705, 1600, 1499, 1252, 1146, 1024, 842, 758 cm⁻¹. UV-Vis: (EtOAc) λ (lge) = 350 nm (4.376).
**COMPOUND 11**

(E-3-((4-(hexyloxy)phenyl)diazeny)benzoic acid (11). To a solution of 10 (4.5 g, 11 mmol) in boiling EtOH (50 mL) was gradually added an aqueous solution of KOH (3N, 30 mL), and refluxed for 24 h. The solution was cooled to rt and acidified (HCl 37%, 2 mL) to precipitate a yellow solid that was collected by filtration, rinsed, and dried under high-vacuum. Yield: 3.44 g (10.5 mmol, 96%); Rf 0.2 (silica gel; EtOAc–nHex, 20% v/v). 1H NMR (600 MHz, CDCl3): δ 8.62 (s, 1H), 8.19 (d, J = 7.8 Hz, 1H), 8.13 (d, J = 7.8 Hz, 1H), 7.95 (d, J = 8.7 Hz, 2H), 7.62 (t, J = 8.2 Hz, 1H), 7.02 (d, J = 8.5 Hz, 2H), 4.06 (t, J = 6.8 Hz, 2H), 1.79–1.88 (m, 2H, CH2), 1.45–1.53 (m, 2H, CH2), 1.32–1.46 (m, 4H, CH2), 0.93 (t, J = 7.3 Hz, 3H). 13C{1H} NMR (150 MHz, CDCl3): δ 171.8, 162.3, 152.9, 146.8, 131.6, 130.4, 129.3, 127.6, 125.2, 124.6, 114.9, 68.5, 31.7, 29.3, 25.8, 22.7, 14.1. MS (ESI+, Quadrupole): m/z [M + H]+ calcld for [C13H12N3O5]+: 325.17, found 325.1; [ESI–, Quadrupole]: m/z [M – H]– calcld for [C13H12N3O5]–: 325.16, found 325.1. IR (neat): 3060, 2942, 2918, 2854, 1694, 1604, 1503, 1447, 1409, 1257, 1142, 843 cm–1. UV-Vis: (EtOAc) λ = 351 nm. Mp: 141–143°C.

**COMPOUND 12**

(E)-3-((4-(hexyloxy)phenyl)diazeny)benzoyl chloride (12). A solution of 11 (3.44 g, 10.5 mmol) in SOCl2 (40 mL) refluxed for 6 h. The excess of SOCl2 was removed by distillation and the residue was diluted with dry DMF (50 mL) and cooled down to –20°C to obtain 12 as shiny orange crystals. Yield: 3.3 g, (9.6 mmol, 92%); Rf (too reactive). 1H NMR (400 MHz, CDCl3): δ 8.59 (s, 1H), 8.16 (d, J = 7.2 Hz, 2H), 7.94 (d, J = 8.7 Hz, 2H), 7.63 (t, J = 7.7 Hz, 1H), 7.01 (d, J = 8.7 Hz, 2H), 4.05 (t, J = 6.7 Hz, 2H), 1.79–1.88 (m, 2H, CH2), 1.45–1.53 (m, 2H, CH2), 1.32–1.56 (m, 4H, CH2), 0.93 (t, J = 6.7 Hz, 3H). 13C{1H} NMR (100 MHz, CDCl3): δ 168.2, 162.5, 153.0, 146.6, 134.3, 132.2, 129.7, 128.9, 125.6, 125.3, 123.9, 31.6, 31.4, 29.2, 25.7, 22.7, 14.1. MS (ESI+; iPrOH, Quadrupole): m/z [M + H]+ calcld for [C6H23Cl2O4]+: 345.13, found 345.1; [ESI–] calcld for [C6H23Cl2O4]–: 345.2, found 345.2. UV-Vis: (EtOAc) λ = 355 nm. IR (neat): 2946, 2868, 1742, 1597, 1498, 1472, 1451, 1247, 1141, 783, 673 cm–1.

**COMPOUND 13**

8-hydroxy-6H,12H-5,11-ethanodibenzo[b,f][1,5]diazocin-2-yl(E)-3-((4-(hexyloxy)phenyl)diazeny) benzoate (13). Solutions of 12 (0.27 g, 1 mM) in dry DMF (3 mL) and 12 (0.76 g, 2.2 mmol) in dry pyridine (3 mL) were combined and stirred overnight under argon atmosphere. The solution was diluted with DCM (50 mL) and rinsed with NaHCO3 (3 M, 3 × 50 mL). The DMF layer dried over MgSO4, filtered, and evaporated to dryness. The crude was chromatographed to obtain 13 as an orange solid. Yield: 0.48 g (0.83 mmol, 83%); Rf 0.3 (silica gel; MeOH – DCM = 4% v/v). 1H NMR (400 MHz, CDCl3): δ 8.60 (t, J = 1.7 Hz, 1H, CH), 8.16–8.20 (m, 1H, CH), 8.08–8.12 (m, 1H, CH), 7.91–7.94 (m, 2H, CH), 7.58–7.63 (m, 1H, CH), 7.16–7.20 (m, 1H, CH), 6.95–7.04 (m, 4H, CH2), 6.83 (d, J = 2.8 Hz, 1H, CH), 6.52 (dd, J = 8.6 Hz, J = 2.8 Hz, 1H, CH), 6.39 (d, J = 2.8 Hz, 1H, CH), 4.36–4.66 (m, 4H, CH2), 4.04 (t, J = 6.8 Hz, 2H, CH2), 3.53–3.66 (m, 4H, CH2), 1.78–1.85 (m, 2H, CH2), 1.44–1.52 (m, 2H, CH2), 1.33–1.38 (m, 4H, CH2), 0.92 (t, J = 7.0 Hz, 3H, CH3). 13C{1H} NMR (100 MHz, CDCl3): δ 164.9, 162.3, 152.0, 147.8, 147.1, 146.7, 138.7, 138.1, 137.9, 131.5, 130.6, 129.4, 129.1, 129.0, 127.7, 127.4, 125.2, 124.2, 123.3, 121.6, 120.5, 115.0, 114.9, 114.6, 68.5, 59.2, 55.0, 31.7, 29.2, 25.8, 22.7, 14.1. MS (ESI+, Quadrupole): m/z [M + H]+ calcld for [C35H36N4O2]+: 577.28, found: 577.3. IR (neat): 2919, 2861, 1734, 1598, 1489, 1290, 1142, 838, 816, 749, 680 cm–1. UV-Vis: (EtOAc) λ (lge) = 350nm (4.421). Anal. Calcld for C35H36N4O2: C, 72.90; H, 6.29; N, 9.72. Found: C, 73.12; H, 6.48; N, 9.53. Enantiomer (+)-(R,R)-13: [α]D20 +351 (c 0.100, EtOAc) obtained from (+)-(R,R)-4; Enantiomer (−)-(S,S)-13: [α]D20 −345 (c 0.100, EtOAc) obtained from (−)-(S,S)-4.
COMPOUND 14
6H,12H-5,11-ethanodibenzo[b,f][1,5]diazocine-2,8-diyl bis 3-((E)-(4-(hexyloxy)phenyl)diazenyli benzoate (14). Obtained from compounds 4 (0.27 g, 1.0 mmol) and 12 (1.14 g, 3.3 mmol, excess) using the procedure described for 13. Yield: 0.65 g (0.73 mmol, 73%); Rf 0.4 (Silica gel; MeOH–DCM= 2% v/v). 1H NMR (600 MHz, CDCl3): δ 8.62 (s, 2H), 8.19 (d, J = 7.8 Hz, 2H), 8.11 (d, J = 7.8 Hz, 2H), 7.94 (d, J = 8.9 Hz, 4H), 7.61 (t, J = 8.0 Hz, 2H), 7.26 (d, J = 8.0 Hz, 2H), 7.00 (d, J = 8.0 Hz, 2H), 7.00 (d, J = 8.9 Hz, 4H), 6.88 (s, 2H), 4.66 (d, J = 17.5 Hz, 2H), 4.49 (d, J = 17.5 Hz, 2H), 4.04 (t, J = 6.5 Hz, 4H), 3.63–3.72 (m, 4H), 1.78–1.85 (m, 4H), 1.45–1.51 (m, 4H), 1.34–1.38 (m, 8H), 0.92 (t, J = 6.8 Hz, 3H). 13C[1H] NMR (150 MHz, CDCl3): δ 164.8, 162.3, 152.9, 147.9, 146.7, 131.5, 130.6, 129.4, 128.9, 127.5, 125.2, 124.2, 121.7, 120.8, 114.9, 114.4, 68.5, 59.2, 54.6, 31.7, 29.2, 25.8, 22.7, 14.1. MS (ESI +, Quadrupole): m/z [M + H]+ calcd for [C54H32N6O16]: 885.43, found: 885.4. IR (neat): 2925, 2859, 1729, 1599, 1489, 1291, 1142, 834, 817, 749, 680 cm⁻¹. Mp: 80–82 °C. UV-Vis: (DCM) λ (lgε) = 353 nm (4.725). Anal. Calcd for C54H32N6O16: C, 73.28; H, 6.38; N, 9.50. Found: C, 73.13; H, 6.47; N, 9.82. Enantiomer (+)-(R,R)-14: [α]D²⁹ +319 (c 0.100, DCM) obtained from (+)-(R,R)-4; Enantiomer (−)-(S,S)-14: [α]D²⁹ −319 (c 0.100, DCM) obtained from (−)-(S,S)-4.

COMPOUND 15
(E)-4-((4-(hexyloxy)phenyl)diazenyli benzoic acid (15). The procedures described the synthesis of 10 and 11 were started with 4-aminobenzoic acid to obtain 15 as an orange solid. Yield: 2.39 g (10.4 mmol, 95%); Rf 0.3 (silica gel; EtOAc–nHex, 30% v/v). 1H NMR (400 MHz, DMSO-d6): δ 8.12 (d, J = 8.4 Hz, 2H), 7.89 (d, J = 8.4 Hz, 2H), 7.88 (d, J = 7.8 Hz, 2H), 7.11 (d, J = 7.8 Hz, 2H), 4.09 (t, J = 6.5 Hz, 2H), 1.72–1.78 (m, 2H), 1.40–1.48 (m, 2H), 1.28–1.38 (m, 4H), 0.89 (t, J = 6.8 Hz, 3H). 13C[1H] NMR (100 MHz, DMSO-d6): δ 167.3, 161.7, 154.3, 146.0, 132.0, 130.0, 124.4, 121.6, 114.8, 67.9, 30.4, 28.1, 24.6, 21.5, 13.2. IR (neat): 3068, 2940, 2828, 1688, 1523, 1445, 1408, 134, 1261, 1143, 867 cm⁻¹. MS (ESI +, Quadrupole): m/z [M + H]+ calcd for [C19H12N2O3]: 327.17, found 327.2; [ESI −, Quadrupole]: m/z [M − H]+ calcd for [C19H12N2O3]: 325.15, found 325.1. Mp: 219–221 °C. UV-Vis: (EtOAc) λ (lgε) = 360nm (4.384).

COMPOUND 16
(E)-4-((4-(hexyloxy)phenyl)diazenyli benzoyl chloride (16). Obtained from 15 (2.39 g, 10.4 mmol) applying the preparation procedure of 12. Yield: 2.93 g (8.53 mmol, 82%); Rf (reacts). 1H NMR (400 MHz, DMSO-d6): δ 8.12 (d, J = 8.4 Hz, 2H), 7.92 (d, J = 8.8 Hz, 2H), 7.90 (d, J = 8.4 Hz, 2H), 7.13 (d, J = 8.8 Hz, 2H), 4.08 (t, J = 6.5 Hz, 2H), 1.70–1.77 (m, 2H), 1.38–1.45 (m, 2H), 1.20–1.35 (m, 4H), 0.88 (t, J = 6.8 Hz, 3H). 13C[1H] NMR (100 MHz, DMSO-d6): δ 166.7, 162.1, 154.5, 146.1, 132.1, 130.6, 125.0, 122.2, 115.1, 68.1, 40.0, 28.5, 25.1, 22.1, 13.9. MS (ESI +, MeOH, Quadrupole): m/z [M − Cl + MeOH]+ calcd for [C20H21N2O3]: 341.18, found 341.2. Anal. (Unstable), IR (neat): 2950, 2871, 1738, 1601, 1487, 1453, 1142, 856, 773, 608 cm⁻¹. UV-Vis: (EtOAc) λ = 355 nm.
COMPOUND 17
6H,12H-5,11-ethanodibenzo[b,f][1,5]diazocine-2,8-diyldbis(4-((E)-4-(hexyloxy)phenyl)diazeneyl) benzoate (17). Obtained from compounds 4 (0.27 g, 1.0 mmol) and 16 (1.14 g, 3.3 mmol, excess) applying the preparation procedure of 14. Yield: 0.71 g (0.81 mmol, 81%); Rt 0.4 (Silica gel; MeOH–DCM = 2% v/v). 1H NMR (400 MHz, CDCl3): δ 8.26 (d, J = 8.6 Hz, 4H), 7.95 (d, J = 8.9 Hz, 4H), 7.94 (d, J = 8.6 Hz, 4H), 7.25 (s, 2H), 7.07 (d, J = 6.7 Hz, 2H), 7.02 (d, J = 8.9 Hz, 4H), 6.91 (d, J = 6.7 Hz, 2H), 4.72 (d, J = 16.9 Hz, 2H), 4.55 (d, J = 16.9 Hz, 2H), 4.06 (t, J = 6.6 Hz, 4H), 3.77 (b, 4H), 1.79–1.86 (m, 4H), 1.45–1.53 (m, 4H), 1.34–1.38 (m, 8H), 0.92 (t, J = 6.8 Hz, 6H). 13C(1H) NMR (100 MHz, CDCl3): δ 164.6, 162.6, 156.0, 146.9, 131.3, 130.1, 127.7, 125.4, 125.2, 124.9, 124.8, 122.6, 122.2, 114.9, 68.3, 63.2, 59.1, 31.7, 29.2, 25.8, 22.7, 14.1. MS (ESI +, Quadrupole): m/z [M + H]+ calcd for [C44H54N8O6]+: 885.43, found: 885.4. IR (neat): 2929, 2859, 1730, 1597, 1488, 1297, 1135, 1066, 861, 835, 689 cm⁻¹. UV-Vis: (DCM) λ (lgε) = 364nm (4.709). Anal. Calcd for C₅₄H₇₅N₁₀O₆: C, 73.28; H, 6.38; N, 9.50. Found: C, 72.96; H, 6.35; N, 9.42. Enantiomer (+(R,R)-17: [α]₀°+468 (c 0.100, DCM) obtained from (+)-(R,R)-4; Enantiomer (−)-(S,S)-17: [α]₀°−473 (c 0.100, DCM) obtained from (−)-(S,S)-4.

COMPOUND 18
(E)-4-((4-butylphenoxy)diazenyl)-2,6-dimethylphenol (18). Synthesized similarly to compound 5 except using 2,6-dimethylphenol (1.2 g, 10 mmol) instead of n-benzylmethylamine. Yield: 2.03g (7.2 mmol, 89%); Rt 0.2 (silica gel; EtOAc–nHex, 5% v/v). 1H NMR (400 MHz, CDCl3): δ 7.83 (d, J = 7.9, 2H), 7.67 (s, 2H), 7.30 (d, J = 7.9, 2H), 4.50 (b, 1H, OH), 2.68 (t, J = 7.7, 2H), 2.32 (s, 6H), 1.60–1.68 (m, 2H), 1.33–1.44 (m, 2H), 0.95 (t, J = 7.5, 3H). 13C(1H) NMR (100 MHz, CDCl3): δ 146.3, 145.9, 130.2, 129.2, 123.9, 123.8, 122.8, 122.5, 35.7, 33.6, 22.5, 16.1, 14.1. MS (ESI +, Quadrupole): m/z calcd for [C18H17N2O1]: 283.18; found: 283.1 (ESI →, Quadrupole); m/z calcd for [C18H17N2O1]: 281.16; found: 281.1. IR (neat): 3343, 2958, 2915, 2853, 1590, 1468, 1197, 1112, 885, 833, 728 cm⁻¹. Mp: 50–51 °C. UV-Vis: (DCM) λ = 354nm. Anal. Calcd for C18H17N2O: C, 76.56; H, 7.85; N, 9.92. Found: C, 76.42; H, 7.96; N, 9.73.

COMPOUND 19
(E)-1-(4-(2-bromoethoxy)-3,5-dimethylphenyl)-2-(4-butylphenyl)diazene (19). Compound 18 (1.13 g, 4.0 mmol) was added to a mixture of K2CO3 (1.2 g, 9.0 mmol), freshly prepared 9a 1,2-dibromoethane (5 mL, excess), KI (0.17 g, 1.14 mmol), and acetone (25 mL), and refluxed for 24 h. The reaction mixture was cooled, filtered and reduced under high-vacuum to obtain a dark red residue that was then chromatographed to obtain 19 as a red oil. Yield: 1.42 g (3.68 mmol, 92%); Rt 0.6 (silica gel; EtOAc–nHex, 5% v/v). 1H NMR (400 MHz, CDCl3): δ 7.81 (d, J = 7.9, 2H), 7.60 (s, 2H), 7.31 (d, J = 7.9, 2H), 4.15 (t, J = 6.1, 2H), 3.69 (t, J = 6.1, 2H), 2.69 (t, J = 7.5, 2H), 2.40 (s, 6H), 1.60–1.70 (m, 2H), 1.34–1.44 (m, 2H), 0.95 (t, J = 7.2, 3H). 13C(1H) NMR (100 MHz, CDCl3): δ 157.4, 151.1, 149.2, 146.3, 131.7, 129.2, 123.5, 122.8, 71.8, 35.7, 33.6, 30.1, 22.5, 16.7, 14.1. MS (ESI +, Quadrupole): m/z calcd for [C20H19BrN2O]: 389.12 and 391.12; found: 389.1 and 391.1. IR (neat): 2955, 2926, 2858, 1600, 1472, 1286, 1199, 1115, 1002, 838, 768 cm⁻¹. UV-Vis: (DCM) λ (lgε) = 343nm (4.342). Anal. Calcd for C20H19BrN2O: C, 61.70; H, 6.47; N, 7.20. Found: C, 61.82; H, 6.33; N, 7.04.
COMPOUND 20
2,8-bis(2-(4-(E)-(4-butylphenyl)diazenyl))-2,6-dimethylphenoxy ethoxy)-6H,12H-5,11-ethanodibenzob[b,f][1,5]diazocine (20). Compounds 4 (0.27 g, 1.0 mmol), 19 (0.97 g, 2.5 mmol), K2CO3 (0.62 g, 4.5 mmol), dry DMF (10 mL), and KI (0.17 g, 1.0 mmol) were mixed, and stirred at 65 °C overnight. The reaction mixture was cooled to rt, mixed with NaHCO3 solution (3N, 50 mL), and extracted with DCM (3 × 30 mL). The collected DCM layers were combined, dried over MgSO4, and filtered. The residue was removed, and the residue was purified by column chromatography to obtain 20 as a light-orange solid. Yield: 0.74 g (0.84 mmol, 84%); Rf 0.5 (silica gel; MeOH – DCM, 2% v/v). 1H NMR (400 MHz, CDCl3): δ 7.79 (d, J = 8.1 Hz, 4H), 7.58 (s, 4H), 7.30 (d, J = 8.1 Hz, 4H), 7.15 (d, J = 8.3 Hz, 2H), 6.70 (dd, J = 8.3, 2.6 Hz, 2H), 6.51 (d, J = 2.6 Hz, 2H), 4.58 (d, J = 17.2 Hz, 2H), 4.40 (d, J = 17.2 Hz, 2H), 4.24–4.15 (b, 4H), 4.14–4.07 (b, 4H), 3.57–3.67 (b, 4H), 2.67 (t, J = 2.6 Hz, 4H), 2.34 (s, 12H), 1.60–1.68 (m, 4H), 1.33–1.42 (m, 4H), 0.94 (t, J = 7.4 Hz, 6H). 13C[1H] NMR (100 MHz, CDCl3): δ 157.9, 156.0, 151.1, 148.9, 146.2, 131.8, 130.7, 129.1, 128.9, 128.6, 123.4, 122.7, 114.6, 113.6, 70.7, 67.3, 59.5, 54.7, 35.6, 33.5, 22.4, 16.5, 14.0. MS (ESI +, Quadrupole): m/z calcd for [C56H56N2O3]+: 885.50; found: 885.5. IR (neat): 2923, 2856, 1602, 1492, 1270, 1195, 1116, 1063, 890, 839 cm–1. Mp: 70–71 °C. UV-Vis: (DCM) λ (Ige) = 344nm (4.687). Anal. Calcd for C56H56N2O3: C, 75.99; H, 7.29; N, 9.49. Found: C, 76.12; H, 7.08; N, 9.63. Enantiomer (+)-(R,R)-20: [α]25D +236 (c 0.100, DCM) obtained from (+)-(R,R)-4; Enantiomer (−)-(S,S)-20: [α]26D −241 (c 0.100, DCM) obtained from (−)-(S,S)-4.

COMPOUND 21
(E)-4-[[2-(octyloxy)naphthalen-1-yl)diazenyl]benzoic acid (21). 4-Aminobenzoic acid (2.0 g, 15 mmol) in HCl solution (7.4%, 100 mL) cooled down to –5 °C. NaNO2 (1.1 g, 16 mmol, in ice-cold water 10 mL) was gradually added and the reaction mixture stirred for 30 min. The obtained solution was added to a fresh solution of 1-naphthol (2.2 g, 15 mmol) and Na2CO3 (2.1 g, 20 mmol) in 40 mL of cold water, and stirred for 4 h. Added HCl (37%, 2mL) to precipitate out a red solid that was then collected by filtration, rinsed with water, and dried under high-vacuum. Rf 0.1 (silica gel; MeOH – DCM, 4% v/v). MS (ESI –, Quadrupole): m/z calcd for [C76H66N2O3]: 291.07; found: 291.2. The crude was added to a mixture of K2CO3 (6.2 g, 45 mmol), 1-octylbromide (7.7 g, 40 mmol), and KI (0.17 g, 1.0 mmol, cat) in dry DMF (80 mL), and stirred for 18 h at 70 °C. The reaction mixture cooled to rt, filtered and reduced under high-vacuum at 60 °C to obtain a dark red residue which was then chromatographed to obtain a brown waxy solid. Rf 0.7 (silica gel; EtOAc – nHex, 10% v/v). MS (ESI +, Quadrupole): m/z calcd for [C56H36N2O3]+: 517.34; found: 517.3. This product was then dissolved in boiling iPrOH (50 mL) and an aqueous solution of KOH (6N, 20mL) was gradually added to its solution, and refluxed for 48 h. Afterward, the solution was acidified by the addition of concd HCl to precipitate 21 as a deep red solid that was collected by filtration, rinsed with water, dried under high-vacuum, and then recrystallized from DCM – nHex 30% v/v. Yield: 3.7 g (9.3 mmol, 62%); Rf 0.4 (silica gel; EtOAc – nHex, 40% v/v). 1H NMR (600 MHz, DMSO-d6): δ 13.16 (b, 1H), 8.90 (d, J = 8.4 Hz, 1H), 8.23 (d, J = 8.4 Hz, 1H), 8.14 (d, J = 8.5 Hz, 2H), 8.02 (d, J = 8.5 Hz, 2H), 7.90 (d, J = 8.5 Hz, 1H), 7.73 (t, J = 7.6 Hz, 1H), 7.62 (t, J = 7.6 Hz, 1H), 7.43 (d, J = 8.5 Hz, 1H), 4.18 (t, J = 6.3 Hz, 2H), 1.78–1.88 (m, 2H), 1.42–1.51 (m, 2H), 1.18–1.35 (m, 8H), 0.83 (t, J = 6.6 Hz, 3H). 13C[1H] NMR (150 MHz, DMSO-d6): δ 166.8, 158.2, 154.9, 154.0, 132.1, 132.0, 130.6, 128.0, 126.1, 124.9, 122.6, 122.4, 121.8, 113.7, 105.1, 68.4, 31.2, 28.7, 28.6, 28.5, 25.6, 22.1, 13.9. MS (ESI +, Quadrupole): m/z [M + H]+ calcd for [C56H56N2O3]: 405.21; found 405.2. IR (neat): 3073, 2963, 2917, 2844, 1692, 1603, 1488, 1249, 1148, 840 cm–1. Mp: 207–209 °C. UV-Vis: (DCM) λ (Ige) = 420nm (4.471) and 283nm (4.436).
COMPOUND 22
6H,12H-5,11-ethanodibenzo[b,f][1,5]diazocine-2,8-diy l bis(4-((E)-4-(octyloxy)naphthalen-1-yl)diazenyl)benzoate (22). Compounds 4 (0.27 g, 1.0 mmol), 21 (0.89 g, 2.2 mmol), N-(3-dimethyl aminopropyl)-N’-ethylecarbodiimide hydrochloride (0.42 g, 2.2 mmol), 4-(dimethylamino)pyridine (0.12 g, 1.0 mmol) stirred in dry DCM (50 mL), 0–5 °C, 2 d. The solvent was removed under reduced pressure, NaHCO₃ solution (3N, 50 mL) was added, and then extracted with DCM (3 × 30 mL). The collected organic layers were combined, dried over MgSO₄, and filtered. The solvent was removed, and the residue was chromatographed to obtain 22 as a red solid. Yield: 0.81 g (0.78 mmol, 78%); Rf 0.7 (silica gel; EtOAc – nHex, 40% v/v). ¹H NMR (600 MHz, CDCl₃): δ 8.98 (d, J = 8.4 Hz, 2H), 8.36 (d, J = 8.4 Hz, 2H), 8.30 (d, J = 8.8 Hz, 4H), 8.06 (d, J = 8.8 Hz, 4H), 7.97 (d, J = 8.4 Hz, 2H), 7.70 (t, J = 7.6 Hz, 2H), 7.59 (t, J = 7.6 Hz, 2H), 7.28 (d, J = 8.4 Hz, 2H), 7.03 (d, J = 8.4 Hz, 2H), 6.90 (s, 2H), 6.88 (d, J = 8.4 Hz, 2H), 4.67 (d, J = 17.5 Hz, 2H), 4.51 (d, J = 17.5 Hz, 2H), 4.22 (t, J = 6.4 Hz, 4H), 3.61–3.74 (m, 4H), 1.91–1.99 (m, 4H), 1.53–1.63 (m, 4H), 1.25–1.47 (m, 16H), 0.91 (t, J = 6.9 Hz, 6H). ¹³C(¹H) NMR (150 MHz, CDCl₃): δ 164.8, 159.0, 156.3, 148.0, 147.0, 141.6, 137.5, 133.1, 130.3, 128.9, 127.9, 127.7, 125.9, 125.8, 123.3, 123.1, 122.4, 121.7, 120.8, 113.8, 104.5, 68.8, 59.2, 54.5, 31.9, 29.5, 29.3, 29.2, 26.3, 22.7, 14.2. MS (ESI +, Quadrupole): m/z [M + H]⁺ calcd for [C₈H₁₄N₂O₄]⁺: 1041.52, found 1041.5. IR (neat): 2922, 2854, 1732, 1574, 1508, 1318, 1237, 1137, 1065, 760 cm⁻¹. Mp: 230–231 °C. UV-Vis: (DCM) λ (lgε) = 423nm (4.802) and 284nm (4.693). Enantiomer (+)-(R,R)-22: [α]D +88° +564° (c 0.100, DCM) obtained from (+)-(R,R)-4; Enantiomer (−)-(S,S)-22: [α]D −78° −571° (c 0.100, DCM) obtained from (−)-(S,S)-4.

References and Notes

10 CCDC 1902224 and 1902226 contain crystallographic data for this work; These data can be obtained free of charge via www.ccdc.cam.ac.uk (or from the Cambridge Crystallographic Data Centre, 12, Union Road, Cambridge CB2 1EZ, UK; fax: +441223 336033).