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# Synthesis and spectroscopic properties of highly water-soluble perylene derivatives

Antonello Alvino,[a] Marco Franceschin,[a,*] Chiara Cefaro,[a] Silvia Borioni,[a] Giancarlo Ortaggi[a] and Armandodoriano Bianco[a,b]

[a]*Dipartimento di Chimica, Università di Roma 'La Sapienza', Piazzale A. Moro 5, 00185 Roma, Italy*
[b]*Istituto di Chimica Biomolecolare del CNR, Università di Roma 'La Sapienza', Piazzale A. Moro 5, 00185 Roma, Italy*

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**Abstract**—Most known perylene diimides are lipophilic, with few exceptions of hydrophilic derivatives. Even in the latter case, the compounds have limited water solubility and show a strong tendency to self-aggregation. In this paper we present the synthesis of four new perylene derivatives with three and four basic side chains, obtained by functionalizing the bay-area of perylene. These molecules show great solubility in aqueous media as hydrochlorides and their tendency to self-aggregate is remarkably reduced with respect to the previously synthesized two-chained perylene diimides. Their different spectroscopic properties in various solvents and conditions are reported and discussed.


## 1. Introduction

Perylene diimides are highly versatile molecules, which attract a great interest owing to their applications in diverse fields of physical organic chemistry, such as dye lasers,[1] light harvesting arrays,[2] and organic electronic devices.[3,4,5] Furthermore, this class of compounds has been widely studied for biochemical and pharmacological purposes because perylene diimides can be considered as potential antitumor drugs acting as telomerase inhibitors.[6,7] A large class of telomerase inhibitors consist of molecules with an extended aromatic core and flexible basic side chains:[8] the target of this type of molecules is not the enzyme, but its telomeric DNA substrate,[9] which is forced by these molecules to assume unusual secondary structures inaccessible to the enzyme, known as G-quadruplexes.[10] Perylene diimides, with their five condensed aromatic rings and suitable polar side chains, can be included in this group: we have recently[11,12] studied a library of *N*,*N*′-disubstituted perylene diimides having the same perylene core but differently functionalized side chains. We have shown that electrostatic interactions between basic ligand side chains and DNA phosphates play a major role in the formation and stabilization of G-quadruplex structures and in selecting its topology; we also found that different side chains on the perylene core led to different efficiencies in telomerase inhibition. Furthermore, we realized that the side chain basicity plays a significant role in drug–water solubility: the tertiary amine groups

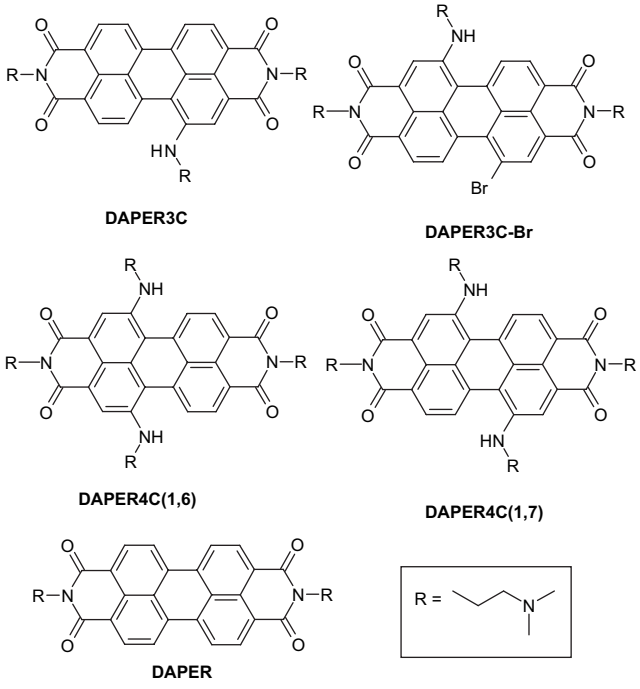


**Figure 1**. The new perylene derivatives with three and four polar side chains and the previously reported DAPER.[11,19]

*Keywords*: Perylene derivatives; Water solubility; Self-aggregation; Absorption spectroscopy.
* Corresponding author. Tel.: +39 0649913341; fax: +39 064462778; e-mail: marco.franceschin@uniroma1.it

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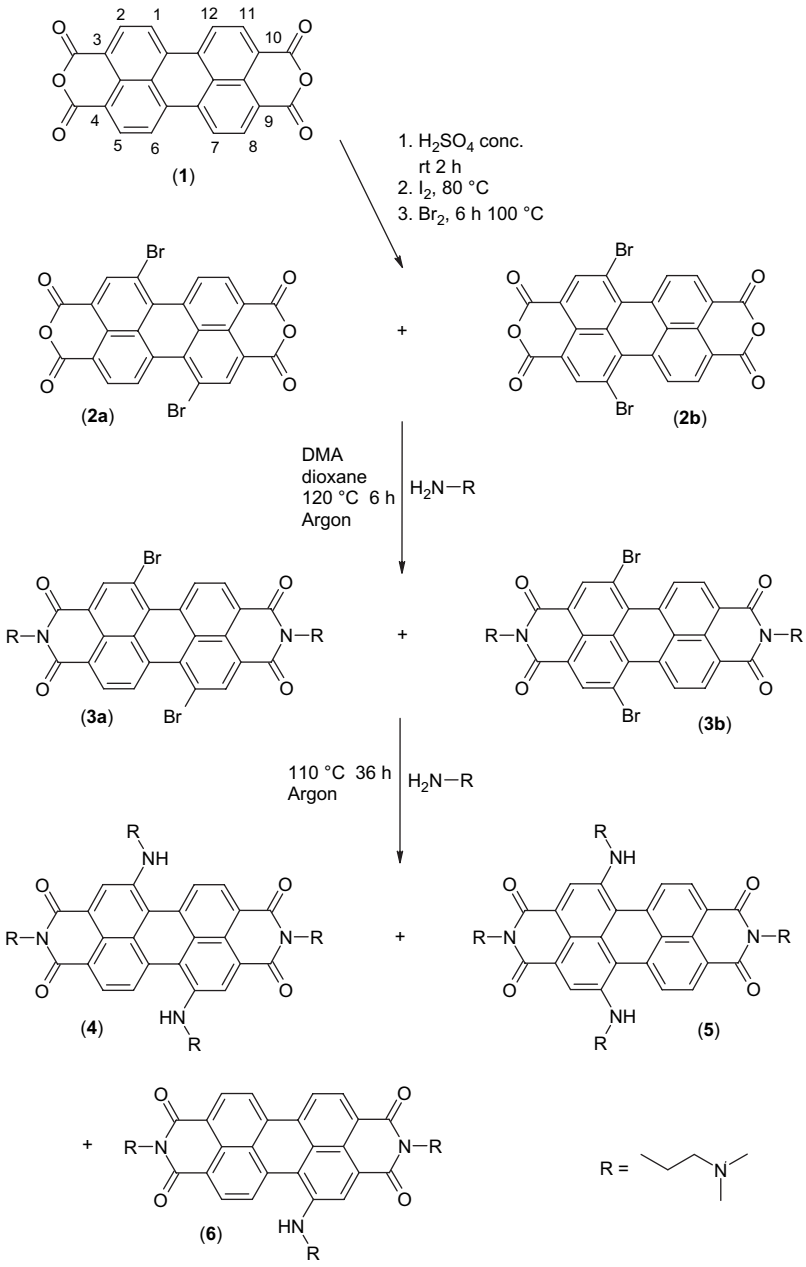


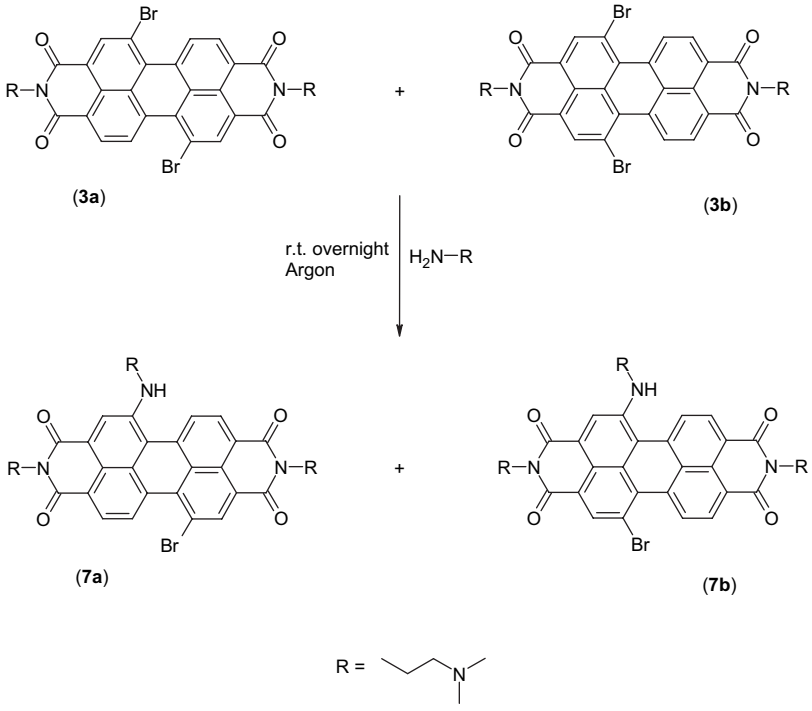

**Scheme 1**.

present in the hydrophilic side chains can be converted to the respective hydrochlorides, leading to a moderate water solubility of the otherwise very hydrophobic perylene core, but these compounds nevertheless undergo extensive self-aggregation in aqueous media.[12] Obviously, for biological applications, water solubility of these compounds is an essential feature:[13] this challenging problem can be resolved by inserting polar side chains on the perylene bay-area. On this basis, we decided to strongly enhance the polarity of the perylene derivatives by increasing the number of basic side chains. In fact, an increased number of polar side chains should lead to enhanced water solubility of the perylene core and to a smaller amount of self-aggregation. In this paper, we present the synthesis of four new perylene derivatives with three and four basic side chains (Fig. 1). As hypothesized, these molecules show great solubility in aqueous media as hydrochlorides and further, their tendency to self-aggregation is remarkably reduced with respect to the previously synthesized two-chained perylene diimides.

## 2. Results and discussion

### 2.1. Synthesis

In order to obtain the designed perylene derivatives, we employed the following strategy: the aromatic area of perylene was functionalized by dibromination[14] of 3,4:9,10-perylenetetracarboxylic dianhydride **1** to obtain 1,7-dibromoperylene-3,4:9,10-tetracarboxylic dianhydride **2a** (Scheme 1). As reported by Würthner and co-workers,[15] we also found a significant amount of the corresponding




**Scheme 2**.

1,6-dibromo isomer **2b**, which was not separable from the 1,7-isomer in this step of the synthesis.[16] The mixture of the two dibromo anhydrides **2a** and **2b** was then reacted with the commercially available 3-dimethylamino-1-propylamine and converted to the respective dibromo diimides **3a** and **3b** (DAPER-Br). In the final step of the synthesis, the diimides **3a** and **3b** were treated with a large excess of the same amine used in the preceding step and heated at 110 °C under argon to perform the displacement of bromine atoms with the nitrogen atoms of the primary amine. This reaction led to a mixture of different products, which were successfully separated by column chromatography: the tetrasubstituted perylene derivatives **4** [DAPER4C(1,7)] and **5** [DAPER4C(1,6)], having the additional chains in the 1,7 and 1,6 positions, respectively, and the trisubstituted derivative **6** (DAPER3C), obtained by partial dehalogenation of the dibromo diimides, a side-reaction also described by Wasielewski and co-workers.[17,18] The attempt to obtain the tetrasubstituted molecules **4** and **5** in a one-pot step, by adding an excess of 3-dimethylamino-1-propylamine to the dibromoperylene anhydrides **2a** and **2b** and heating the mixture at 120 °C, was not successful in the isolation of the desired products. Moreover, we performed the substitution of bromine atoms on the dibromoperylene diimides **3a** and **3b** at room temperature (Scheme 2), and we found that only one bromine atom was readily substituted by the nitrogen of the amine while the other one still remained on the aromatic core even after a long reaction time (12–24 h). In this way, we obtained a mixture of compound **7a** [DAPER3C-Br; 1,7-isomer] and the respective 1,6-isomer **7b**, which present one polar side chain and one bromine atom on the perylene bay-area. This interesting feature could allow the displacement of the two bromine atoms in two separate steps, by different reactants at different temperatures, to yield asymmetric compounds.

## 2.2. Spectroscopic properties

The self-aggregation of the synthesized compounds in solution was examined by UV–vis absorption spectroscopy and NMR at different temperatures and in different solvents. In Figure 2, the absorption spectra of the synthesized compounds in DMSO are shown; the simple unsubstituted perylene diimide DAPER[11,19] (Fig. 1) is also reported for comparison. The spectra of three and four side chain perylene derivatives are characterized by very broad absorption bands over 600 nm, red-shifted with respect to unsubstituted perylene diimides: in fact, these compounds show blue or green colors, both in the solid state and in solution. These bands are typical for perylene derivatives *N*-substituted at the 1,6 and 1,7 positions on the bay-area, due to a charge transfer absorption,[18] as illustrated in Figure 3. Moreover, it has been clearly shown that bay-substituted perylene diimides with two substituents present

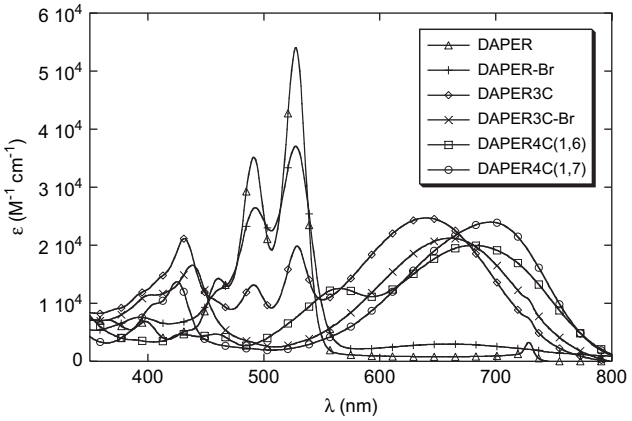



**Figure 2**. UV–vis absorption spectra of the perylene derivatives performed in DMSO.

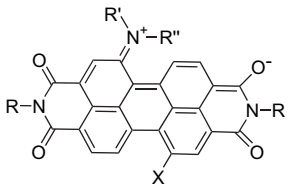



**Figure 3**. One of the possible resonance structures for *N*-bay-substituted perylene derivatives, explaining the charge transfer absorption for these compounds.

a twisting of the two naphthalene subunits in the perylene core by about 20°,[20] as we have also found by molecular modeling (Fig. 4). DAPER-Br (**3**), which does not have the conjugation of the N atom and the aromatic core of perylene, does not present the bathochromic shift of the absorption spectrum, yet it still has a less resolved spectrum with respect to DAPER, since it is supposed to have a core twisting analogous to the other bay-disubstituted derivatives.[20] In fact, the resulting loss of planarity of the perylene chromophore may be responsible for the line broadening of the spectrum and the loss of its fine structure.[21]

Previously, we have reported that the UV–vis spectra of the hydrochlorides of perylene diimides[12] and coronene derivatives[22] show a significant decrease of the molar extinction coefficients in water with respect to organic solvents, because of self-aggregation, despite their water solubility. As a confirmation of this behavior, a detail of the NMR spectra in $D_2O$ of an unsubstituted perylene diimide, characterized by a low resolution in the aromatic region, is reported in Figure 5. On the contrary, the UV–vis spectra in aqueous buffer at pH 6.5 of the new three and four-chained perylene derivatives are very similar to the spectra obtained in organic solvent (Fig. 6). Furthermore, increasing the temperature induces only small changes in the spectra. These data are in agreement with a poor aggregation of the new perylene derivatives in water, in contrast to what happens for the previously reported two-side-chain perylene derivatives.[12] NMR data confirmed this hypothesis, since the NMR spectrum in $D_2O$ of **5** [DAPER4C(1,6)] shows three distinct

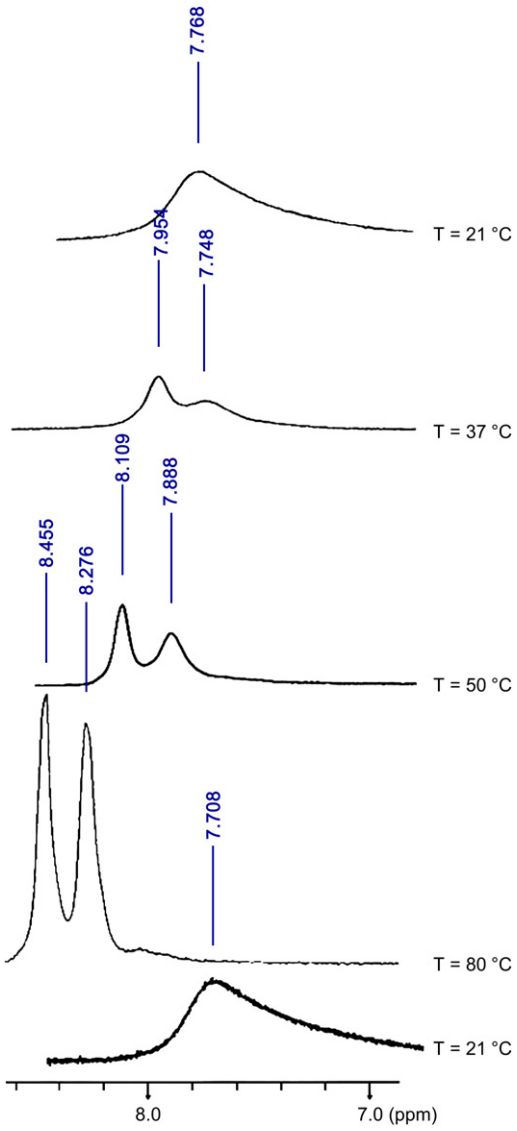



**Figure 5**. Aromatic regions of the $^1H$ NMR spectra of the unsubstituted perylene diimide PIPER3(4HCl)[12] in $D_2O$ at different temperatures. The last one has been recorded after cooling.

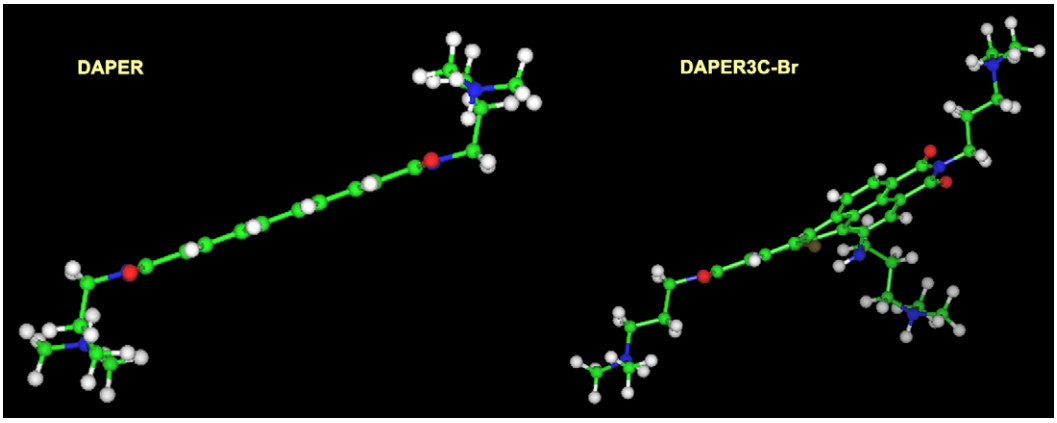



**Figure 4**. Lateral view of the models for DAPER and DAPER3C-Br obtained by conjugate gradient minimization, showing the core twisting in the latter compound, due to both the bromine and the nitrogen substituents.

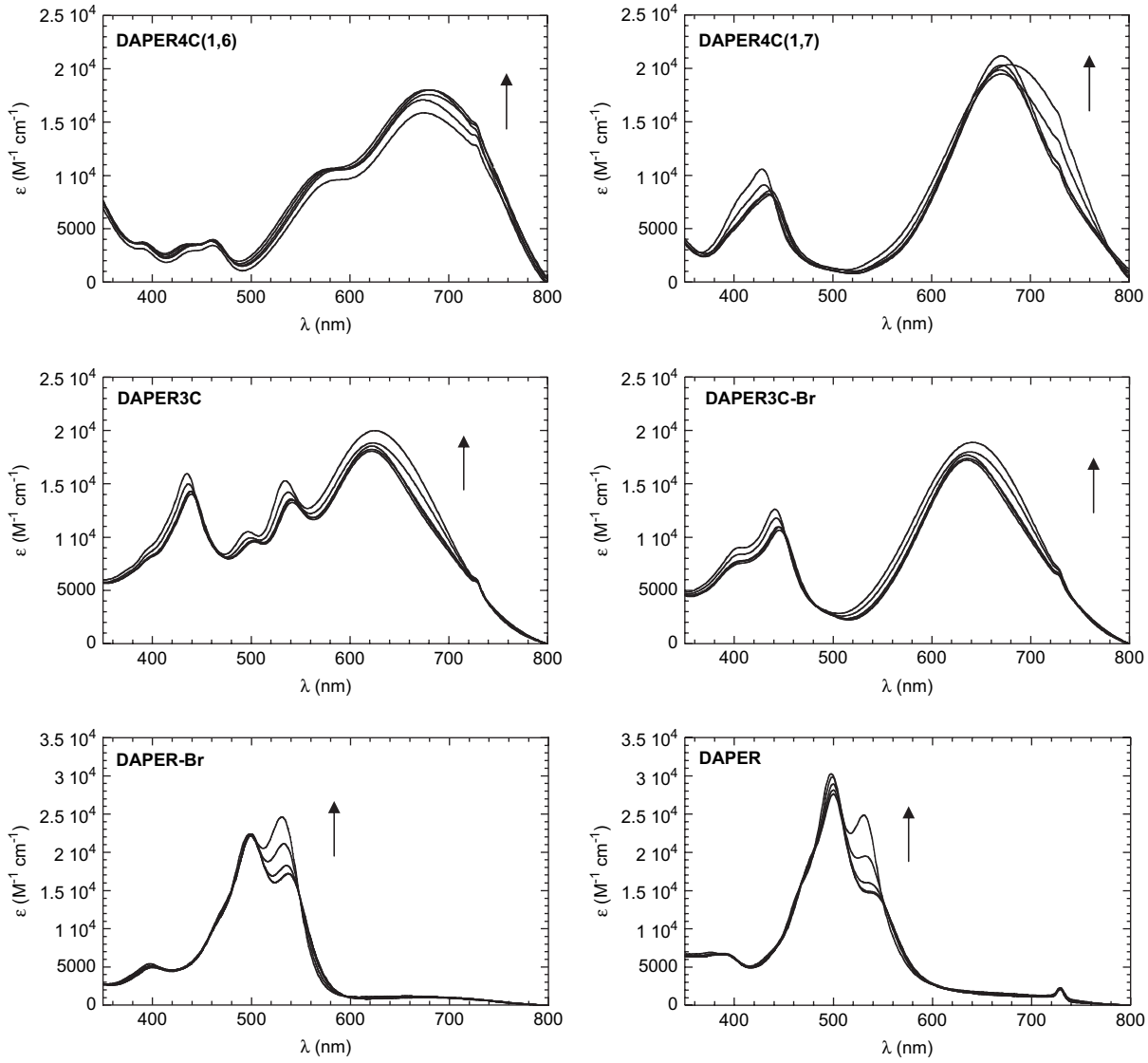



**Figure 6**. UV–vis absorption spectra of the labeled compounds performed in aqueous buffer (pH 6.5) at different temperatures. The arrows indicate an increasing temperature from 25 to 90 °C.

peaks in the aromatic region even at room temperature, correctly proportional to the aliphatic signals (Table 1). Moreover, the NMR spectrum of DAPER4C(1,6) (**5**) in $D_2O$ remains substantially unmodified at three different temperatures (Supplementary data, Figs. S1–S3), differently from what happens for simple perylene diimides (Fig. 5). Furthermore, the lack of self-aggregation is consistent with the linearity of the absorbance in the UV–vis spectra performed at different concentrations (Supplementary data, Fig. S4), in contrast to the two-side-chain perylene derivatives.[12]

The reduced self-aggregation of these new compounds in water can be related to the additional polar side chains introduced on the perylene moiety and the distortion of the planar area of perylene is due to the presence of these side chains on the bay-area. In fact, when in the case of DAPER-Br (**3**) only one of these two effects is present, there is an intermediate situation between the strong tendency to aggregation in water of the unsubstituted perylene diimides and the lack of aggregation of three and four polar side chain perylene derivatives.

**Table 1**. Chemical shifts (ppm) and relative integral values for the main NMR peaks of DAPER4C(1,6) (**5**) in $D_2O$ at the indicated temperatures

| Temperature (°C) | Chemical shift; (integral value) | | | |
|---|---|---|---|---|
| 25 | 8.14, 7.96; (4.0) | 7.48; (1.4) | 4.16; (4.2) | 2.06; (7.8) |
| 40 | 8.33, 8.16; (4.0) | 7.67; (1.5) | 4.32; (3.0) | 2.23; (7.7) |
| 80 | 8.71, 8.58; (4.0) | 8.02; (1.6) | — | 2.58; (8.4) |

Finally, we examined the effect of pH on the visible spectra of the newly synthesized perylene derivatives in water. In fact, while the spectrum of DAPER is substantially unchanged when performed in concentrated HCl with respect to that performed in buffer at pH 6.5, the spectra of three and four side chain derivatives in these conditions mainly lose their typical band over 600 nm in favor of the appearance of the classical carboxylic perylene pattern centered around 500 nm (Fig. 7), as also demonstrated by the pale red color of the analyzed solutions. This is due to the fact that in these conditions even the nitrogen atoms on the bay-area are protonated, so that the charge transfer

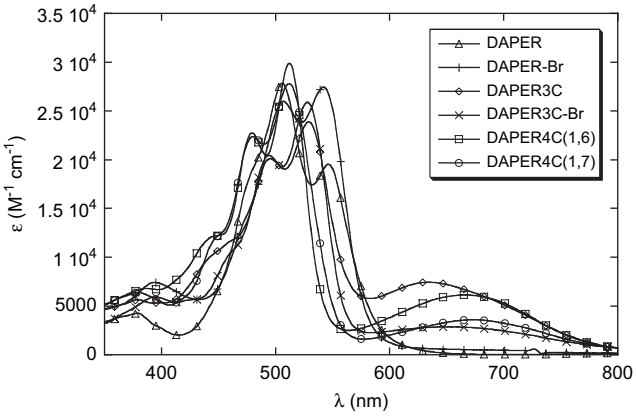



**Figure 7**. UV–vis absorption spectra of the perylene derivatives performed in concentrated HCl.

absorption is no longer possible[23] (Fig. 3). It is also interesting to note that the absorption spectra of three and four side chain perylene derivatives in these conditions are more similar to the spectrum of DAPER in DMSO (monomer, in which the band around 500 nm is weaker than the band around 530 nm) than in water (aggregates), since they retain the lack of self-aggregation. The pH-dependent change of color has been demonstrated to be fully reversible.

## 3. Conclusions

The reported data show that the new three and four basic side chain perylene derivatives described here are characterized by excellent water solubility without aggregation, differently from the previously synthesized two-chained perylene diimides. Their colors range from blue to green in the solid state and in neutral and slightly acid solutions. The broad absorption bands over 600 nm, due to charge transfer absorption, which characterize the UV–vis spectra of these compounds in the above conditions, disappear or are greatly reduced in concentrated acid, when the conjugation of the N atom and the aromatic core of perylene is hindered. Many useful applications can be envisaged for these new compounds, ranging from dyes for microscopic techniques to the quantization of biological macromolecules, as well as G-quadruplex interactive telomerase inhibitors.[24]

## 4. Experimental

### 4.1. Materials

All the commercial reagents and solvents were purchased from Aldrich. TLC plates (silica gel 60 $F_{254}$) and silica gel 60 (0.063–0.200 mm) for column chromatography were purchased from Merck. DAPER[19] was purchased from Pierce, as a 1 mM solution in MES buffer, from which all the dilutions were made.

### 4.2. Equipments

NMR spectra were performed with Varian Gemini 200 and Varian Mercury 300 instruments. High resolution ESI-MS spectra were recorded on Micromass Q-TOF MICRO spectrometer. Elemental analyses (C, H, N) were carried out on EA1110 CHNS-O (CE instruments). UV–vis absorption spectra were performed using a JASCO V-530 spectrophotometer.

### 4.3. UV–vis absorption spectroscopy

UV–vis absorption spectra were registered between 350 and 800 nm in quartz cuvettes. Drug stocks of 1 mM in DMSO were prepared by dissolving the basic form of the compounds in 0.05 M HCl and then diluting 1:10 in DMSO. Final solutions were prepared by suitable dilution of these stocks in DMSO, MES-KCl buffer (10 mM MES, 50 mM KCl, pH=6.5), and concentrated HCl.

### 4.4. Molecular modeling

Molecules were built using the Builder module in InsightII. After CVFF atom and bond types were assigned to the structures, they were energy-minimized (10,000 steps, Polak-Ribiere conjugate gradient) using the Discover_3 module.

### 4.5. Synthesis

**4.5.1. Dibromoperylene-3,4:9,10-tetracarboxylic dianhydrides (2).** The starting material was the commercially available 3,4:9,10-perylenetetracarboxylic dianhydride **1** (5.0 g, 0.013 mol), which was dibrominated as previously described,[14,16] to give a mixture (6.0 g, 87% yield) of 1,7-dibromoperylene-3,4:9,10-tetracarboxylic dianhydride **2a** and the 1,6-dibromo isomer **2b**. The two isomers could not be separated in this synthetic step,[15] so the mixture was used in the following steps without further purification.[16] Optimizing the reaction conditions, we managed to obtain a ratio of 6:1 between the 1,7 (**2a**) and the 1,6 (**2b**) isomers. $^1$H NMR (200 MHz, $D_2SO_4$): $\delta$ 10.71 (d, $J$=8 Hz, 2H, aromatic H), 10.04 (s, 2H, aromatic H), 9.82 (d, $J$=8 Hz, 2H, aromatic H) ppm. The signals of the minor (1,6) isomer (**2b**) are mainly superimposed with those reported for **2a**. Elemental analyses $C_{24}H_6O_6Br_2$, calcd C 52.4%, H 1.1%; found C 51.6%, H 1.1%.

**4.5.2. DAPER-Br (3).** The mixture of the two dibrominated anhydrides **2a** and **2b** (4.0 g, 0.007 mol) was dissolved in anhydrous *N*,*N*-dimethylacetamide (40 ml) and 1,4-dioxane (40 ml). Commercially available 3-dimethylamino-1-propylamine (2 ml, 0.016 mol) was added and the reaction mixture was stirred at 120 °C for 6 h under argon. Upon water addition, a red solid was obtained, washed repeatedly with water, separated by filtration, and dried to give the two diimides **3a** and **3b** (4.4 g, 84% yield).

**4.5.2.1. *N*,*N*′-Bis[3-(dimethylamino)propyl]-1,7-dibromoperylene-3,4:9,10-tetracarboxylic diimide (3a).** $^1$H NMR (300 MHz, $CDCl_3$): $\delta$ 9.44 (d, $J$=8 Hz, 2H, aromatic H), 8.88 (s, 2H, aromatic H), 8.66 (d, $J$=8 Hz, 2H, aromatic H), 4.25 (t, $J$=7 Hz, 4H, $N_{imidic}$–$CH_2$), 2.44 (t, $J$=7 Hz, 4H, $N_{aminic}$–$CH_2$), 2.26 (s, 12H, $N_{aminic}$–$CH_3$), 1.92 (t, $J$=7 Hz, 4H, $N_{imidic}$–$CH_2$–C$H_2$–$CH_2$–$N_{aminic}$) ppm. The signals of the minor (1,6) isomer (**3b**) are mainly superimposed with those reported for **3a**. $^{13}$C NMR ($CDCl_3$): $\delta$ 162.64 (C=O), 162.14 (C=O), 137.80 (ar.), 132.64 (ar.), 132.51 (ar.), 129.78 (ar.), 128.99 (ar.), 128.29 (ar.),

123.07 (ar.), 122.62 (ar.), 120.67 (ar.), 126.74 (ar.), 57.23, 45.34, 39.17, 26.01. MS (ESI) *m/z*: 717.0752 [(M+H)$^+$] (calcd for $C_{34}H_{31}Br_2N_4O_4$: 717.0712).

**4.5.3. Perylene derivatives 4, 5 and 6 Scheme 1.** A mixture of **3a** and **3b** (400 mg, 0.56 mmol) was dissolved in 3-dimethylamino-1-propylamine (12 ml), argon was bubbled through the solution, and the reaction mixture was heated at 110 °C with stirring for 36 h under argon; the color of the solution quickly turned from red to bluish green. After cooling, chloroform was added and the organic layer was repeatedly washed with water. After drying over $Na_2SO_4$ and evaporation in vacuo, the crude product was purified by column chromatography on silica gel ($CHCl_3$/MeOH/$NH_3$ 100:0:0, 98:2:1) to give 20 mg (5% yield) of *N*,*N*′-bis[3-(dimethylamino)propyl]-1,7-bis[3-(dimethylamino)propyl]-perylene-3,4:9,10-tetracarboxylic diimide **4** [(DAPER4C(1,7)], 40 mg (9% yield) of *N*,*N*′-bis[3-(dimethylamino)propyl]-1,6-bis[3-(dimethylamino)propyl]-perylene-3,4:9,10-tetracarboxylic diimide **5** [DAPER4C(1,6)], and 50 mg (14% yield) of the trisubstituted compound **6** *N*,*N*′-bis[3-(dimethylamino)propyl]-1-[3-(dimethylamino)propyl]-perylene-3,4:9,10-tetracarboxylic diimide (DAPER3C).

**4.5.3.1. *N*,*N*′-Bis[3-(dimethylamino)propyl]-1,7-bis-[3-(dimethylamino)propyl]-perylene-3,4:9,10-tetracarboxylic diimide [4, DAPER4C(1,7)].** Amorphous green solid. IR ($CHCl_3$): $\nu$ 2960, 2825, 1686, 1650, 1593, 1516, 1469, 1437, 1354, 1296, 1235 cm$^{-1}$. $^1$H NMR (300 MHz, $CDCl_3$): $\delta$ 8.68 (2H, d, *J*=8 Hz, aromatic H), 8.17 (2H, d, *J*=8 Hz, aromatic H), 7.98 (2H, s, aromatic H), 7.88 (2H, m, N–H), 4.21 (4H, t, *J*=7 Hz, $N_{imidic}$–$CH_2$), 3.41 (4H, m, $N_{aminic}$–$CH_2$), 2.42 (8H, m, $N_{aminic}$–$CH_2$), 2.27 (12H, s, $N_{aminic}$–$CH_3$), 2.10 (12H, s, $N_{aminic}$–$CH_3$), 2.0–1.8 (8H, br, $N_{imidic}$–$CH_2$–C*H*$_2$–$CH_2$–$N_{aminic}$). $^{13}$C NMR ($CDCl_3$): $\delta$ 163.80 (C=O), 163.54 (C=O), 146.35 (ar.), 133.94 (ar.), 129.72 (ar.), 126.17 (ar.), 122.32 (ar.), 121.86 (ar.), 121.85 (ar.), 119.69 (ar.), 117.71 (ar.), 116.89 (ar.), 59.17, 57.37, 45.43, 38.80, 26.14, 25.14. MS (ESI) *m/z*: 761.4518 [(M+H)$^+$] (calcd for $C_{44}H_{57}N_8O_4$: 761.4503).

**4.5.3.2. *N*,*N*′-Bis[3-(dimethylamino)propyl]-1,6-bis-[3-(dimethylamino)propyl]-perylene-3,4:9,10-tetracarboxylic diimide [5, DAPER4C(1,6)].** Amorphous blue solid. IR ($CHCl_3$): $\nu$ 3030, 2865, 1717, 1682, 1647, 1590, 1540, 1466, 1412, 1387, 1355, 1278, 1246 cm$^{-1}$. $^1$H NMR (200 MHz, $CDCl_3$): $\delta$ 8.56 (2H, d, *J*=8 Hz, aromatic H), 8.45 (2H, d, *J*=8 Hz, aromatic H), 8.02 (2H, m, N–H), 7.79 (2H, s, aromatic H), 4.21 (4H, m, $N_{imidic}$–$CH_2$), 3.46 (4H, m, $N_{aminic}$–$CH_2$), 2.42 (8H, m, $N_{aminic}$–$CH_2$), 2.27 (6H, s, $N_{aminic}$–$CH_3$), 2.26 (6H, s, $N_{aminic}$–$CH_3$), 2.13 (12H, s, $N_{aminic}$–$CH_3$), 2.1–1.8 (8H, br, $N_{imidic}$–$CH_2$–C*H*$_2$–$CH_2$–$N_{aminic}$). $^{13}$C NMR ($CDCl_3$): $\delta$ 164.16 (C=O), 163.82 (C=O), 149.12 (ar.), 136.52 (ar.), 130.74 (ar.), 130.41 (ar.), 129.66 (ar.), 129.24 (ar.), 124.41 (ar.), 120.14 (ar.), 117.76 (ar.), 114.58 (ar.), 114.07 (ar.), 113.44 (ar.), 59.26, 57.86, 57.71, 45.84, 45.77, 39.00, 38.80, 26.86, 26.50. MS (ESI) *m/z*: 761.4482 [(M+H)$^+$] (calcd for $C_{44}H_{57}N_8O_4$: 761.4503).

**4.5.3.3. *N*,*N*′-Bis[3-(dimethylamino)propyl]-1-[3-(dimethylamino)propyl]-perylene-3,4:9,10-tetracarboxylic diimide (6, DAPER3C).** Amorphous blue-green solid. IR ($CHCl_3$): $\nu$ 2960, 2825, 1689, 1654, 1594, 1562, 1513, 1438, 1389, 1359, 1282 cm$^{-1}$. $^1$H NMR (200 MHz, $CDCl_3$): $\delta$ 8.56 (1H, d, *J*=8 Hz, aromatic H), 8.4–8.2 (3H, m), 8.1–7.9 (3H, m), 7.83 (1H, s, aromatic H), 4.17 (4H, t, *J*=7 Hz, $N_{imidic}$–$CH_2$), 3.43 (2H, m, $N_{aminic}$–$CH_2$), 2.47 (6H, m, $N_{aminic}$–$CH_2$), 2.28 (6H, s, $N_{aminic}$–$CH_3$), 2.26 (6H, s, $N_{aminic}$–$CH_3$), 2.17 (6H, s, $N_{aminic}$–$CH_3$), 2.0–1.8 (6H, br, $N_{imidic}$–$CH_2$–C*H*$_2$–$CH_2$–$N_{aminic}$). $^{13}$C NMR ($CDCl_3$): $\delta$ 163.45 (C=O), 163.43 (C=O), 163.17 (C=O), 162.87 (C=O), 147.93 (ar.), 136.03 (ar.), 134.92 (ar.), 131.80 (ar.), 130.79 (ar.), 130.41 (ar.), 129.24 (ar.), 127.78 (ar.), 127.05 (ar.), 125.88 (ar.), 123.75 (ar.), 123.46 (ar.), 122.59 (ar.), 121.88 (ar.), 121.35 (ar.), 121.30 (ar.), 120.19 (ar.), 119.35 (ar.), 119.1 (ar.), 114.14 (ar.), 59.34, 57.39, 57.31, 45.45, 45.39, 38.90, 26.14, 24.95. MS (ESI) *m/z*: 661.3490 [(M+H)$^+$] (calcd for $C_{39}H_{45}N_6O_4$: 661.3502).

**4.5.4. *N*,*N*′-Bis[3-(dimethylamino)propyl]-1-bromo-7-[3-(dimethylamino)propyl]-perylene-3,4:9,10-tetracarboxylic diimide [7a, DAPER3C-Br] Scheme 2.** The mixture of the two diimides **3a** and **3b** (300 mg, 0.42 mmol) was dissolved in 3-dimethylamino-1-propylamine (15 ml) and the reaction was carried out overnight, at room temperature under argon. After the same work-up as described above and column chromatography (silica gel, $CHCl_3$/MeOH/$NH_3$ 95:5:0, 95:5:1), 80 mg (26% yield) of *N*,*N*′-bis[3-(dimethylamino)propyl]-1-bromo-7-[3-(dimethylamino)propyl]-perylene-3,4:9,10-tetracarboxylic diimide **7a** (DAPER3C-Br, in the major 1,7-isomer with a very small amount of the respective 1,6-isomer **7b**) was obtained as an amorphous blue-green solid. IR ($CHCl_3$): $\nu$ 2961, 2826, 1691, 1653, 1590, 1565, 1513, 1475, 1443, 1389, 1347, 1287 cm$^{-1}$. $^1$H NMR (200 MHz, $CDCl_3$): $\delta$ 9.05 (1H, d, *J*=8 Hz, aromatic H), 8.95 (*), 8.61 (1H, d, *J*=8 Hz, aromatic H), 8.53 (1H, s, aromatic H), 8.40 (1H, m, N–H), 8.34 (1H, d, *J*=8 Hz, aromatic H), 8.15 (1H, d, *J*=8 Hz, aromatic H), 7.98 (1H, s, aromatic H), 7.95 (*), 4.18 (4H, t, *J*=7 Hz, $N_{imidic}$–$CH_2$), 3.47 (2H, m, $N_{aminic}$–$CH_2$), 2.44 (6H, m, $N_{aminic}$–$CH_2$), 2.26 (12H, s, $N_{aminic}$–$CH_3$), 2.12 (6H, s, $N_{aminic}$–$CH_3$), 2.0–1.8 (6H, br, $N_{imidic}$–$CH_2$–C*H*$_2$–$CH_2$–$N_{aminic}$). (*) Indicates aromatic $^1$H NMR signals due to the minor 1,6-isomer (**7b**). $^{13}$C NMR ($CDCl_3$): $\delta$ 163.32 (C=O), 163.29 (C=O), 162.70 (C=O), 162.38 (C=O), 147.82 (ar.), 137.53 (ar.), 135.07 (ar.), 134.16 (ar.), 130.69 (ar.), 130.37 (ar.), 129.67 (ar.), 128.88 (ar.), 128.23 (ar.), 127.43 (ar.), 124.70 (ar.), 124.16 (ar.), 122.93 (ar.), 121.21 (ar.), 121.16 (ar.), 120.75 (ar.), 118.87 (ar.), 118.51 (ar.), 117.52 (ar.), 113.70 (ar.), 59.12, 57.30, 45.38, 45.35, 38.94, 26.08, 25.99, 24.98. MS (ESI) *m/z*: 739.2596 [(M+H)$^+$] (calcd for $C_{39}H_{44}N_6O_4Br$: 739.2607).

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## Supplementary data

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