Pergamon

Tetrahedron 54 (1998) 11141–11150

TETRAHEDRON

New Pyrimidine and Pyrimidone Derivatives of [60]Fullerene

Augusto C. Tomé,[a*] Roger F. Enes,[a] João P. C. Tomé,[a] João Rocha,[a]
Maria G. P. M. S. Neves,[a] José A. S. Cavaleiro,[a] and José Elguero [b]

[a] *Departamento de Química, Universidade de Aveiro, 3810 Aveiro, Portugal*

[b] *Instituto de Química Médica, CSIC, Juan de la Cierva 3, E-28006, Madrid, Spain*

Received 23 February 1998; revised 25 June 1998; accepted 2 July 1998

Abstract:

Pyrimidine and pyrimidone derivatives of [60]fullerene have been obtained by Diels-Alder reaction of pyrimidine and pyrimidone *o*-quinodimethanes with C_{60}. Fullerene derivatives having hydrophobic or hydrophilic chains were prepared by acylation of one of the adducts. A porphyrin-C_{60} hybrid was also prepared.

Keywords: Diels-Alder reactions; Fullerenes; Porphyrins and analogues; Pyrimidines/pyrimidinones

1- INTRODUCTION

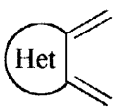
Recent studies on the biochemical and medicinal properties of some fullerene derivatives revealed important biological activities, both *in vitro* and *in vivo*.[1,2] The inhibition of HIV-protease and the site-specific cleavage of DNA are two of the most important applications of these compounds. In a different area, due to its ability to accept electrons, [60]fullerene has been considered as a potential candidate to be used as acceptor in artificial photosynthetic models. Several porphyrin-C_{60} hybrids have been prepared and studied for this purpose.[3-15] It has been demonstrated that C_{60} acts as an effective primary electron acceptor in a carotene-porphyrin-fullerene triad system, generating long-lived charge separated states with reasonable quantum yields.[11]

Recently we described the synthesis of some pyrimidine derivatives of fullerene C_{60}.[16] Considering that pyrimidine derivatives are a group of naturally ocurring compounds with highly significant biological activities one can foresee that pyrimidine derivatives of C_{60} might have important medicinal applications. Our previous work has been extended to the synthesis of other pyrimidine-C_{60} derivatives, including a porphyrin-C_{60} hybrid, and is now reported in detail.

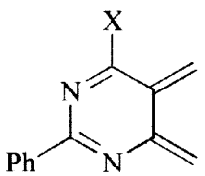
* E-mail: actome@dq.ua.pt Fax: ... + 351 34 25143

0040-4020/98/$ - see front matter
PII: S0040-4020(98)00652-8

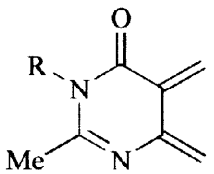
Many of the reports concerning the synthesis of heterocyclic derivatives of fullerene C_{60} involve the Diels-Alder reaction between C_{60} and heterocyclic *o*-quinodimethanes **1**; the versatility of this method for the production of heterocyclic derivatives of C_{60} is confirmed by the range of heterocyclic *o*-quinodimethanes already used with success.[17-20] We have also applied this methodology to the synthesis of pyrimidine and pyrimidone derivatives of C_{60}. The key intermediates, the transient pyrimidine and pyrimidone *o*-quinodimethanes **2** and **3**, were generated *in situ* by thermal extrusion of sulfur dioxide from the corresponding fused 3-sulfolenes **4** and **5**. Another work on the synthesis of pyrimidine-C_{60} derivatives, also involving pyrimidine *o*-quinodimethanes, has been recently published; cyclobutapyrimidines substituted at positions 2 and 4 with two equal groups are used as precursors of the corresponding *o*-quinodimethanes.[21] Although this is an expeditious procedure to prepare some pyrimidine-C_{60} derivatives it lacks the versatility shown by our method.



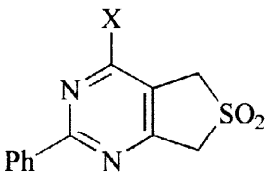
1



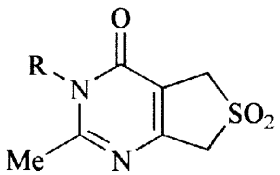
2a, X= OCH_3
2b, X= piperazinyl



3a, R= H
3b, R= CH_3



4a, X= OCH_3
4b, X= piperazinyl



5a, R= H
5b, R= CH_3

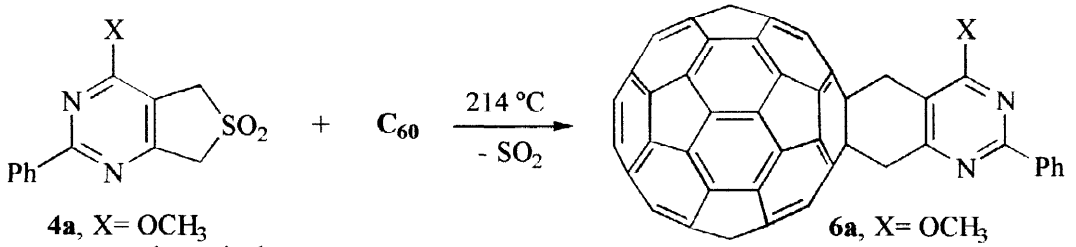
2- RESULTS AND DISCUSSION

2.1- Diels-Alder reaction of pyrimidine and pyrimidone o-quinodimethanes with C_{60}

The pyrimidine [22, 23] and pyrimidone [24, 25] fused 3-sulfolenes **4a**, **5a** and **5b** were prepared as previously reported. The new sulfone **4b** was prepared by a similar procedure (see experimental).

The thermolysis of pyrimidines **4** were done in the presence of C_{60} in refluxing 1,2,4-trichlorobenzene, under a nitrogen atmosphere. When sulfone **4a** was used, the obtained adduct **6a** was separated from the unreacted C_{60} and the trichlorobenzene by column chromatography (silica). After partial evaporation of the eluent, the adduct was precipitated by the addition of hexane, filtered, dried and characterized by ^1H, ^{13}C NMR and MS (LSIMS). Its characterization presented no problem since adduct **6a** is quite soluble in CS_2. In contrast, adduct

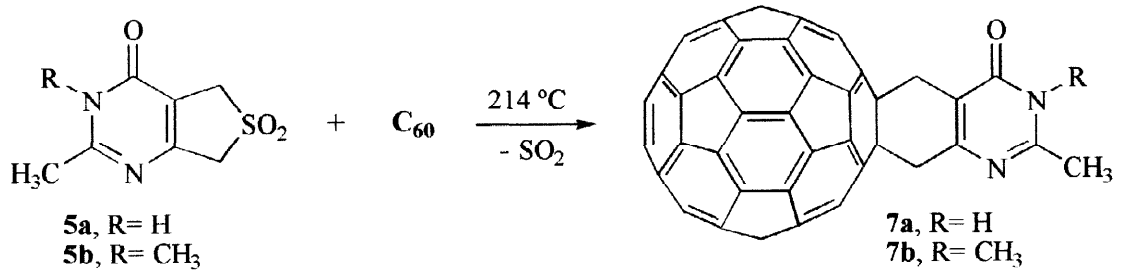
6b could not be purified by column chromatography because of its very low solubility in most solvents. It was precipitated from the reaction mixture by the addition of hexane, filtered and the solid was then purified by refluxing it in chloroform. Its mass spectrum confirmed the expected molecular weight (M+H= 988), but the insolubility of adduct **6b** prevented its characterization by solution NMR. However, the ^{13}C CP/MAS NMR spectrum confirms that the solid is a pyrimidine-C_{60} adduct: it displays a peak at 63.9 ppm (corresponding to the bridgehead fullerene carbons), a peak at 115.2 ppm (corresponding to the carbon 4a of the pyrimidine ring), a peak at 128.7 ppm (corresponding to the phenyl ring carbons), two very strong peaks at 142.7 and 145.2 ppm (corresponding to the fullerene carbons) and three peaks at 154.5, 162.1 and 166.7 ppm (corresponding to the carbons of the pyrimidine ring). Further evidence for the structure of adduct **6b** was obtained by its transformation into other fullerene derivatives (*vide infra*). For instance, the ^{13}C NMR spectrum (solution) of compound **8a** is similar (although more resolved) to the ^{13}C CP/MAS NMR spectrum (solid state) of compound **6b**.



4a, X= OCH_3
4b, X= piperazinyl

6a, X= OCH_3
6b, X= piperazinyl

Thermolysis of pyrimidones **5a** and **5b** in the presence of C_{60}, under similar conditions to those used for the preparation of adducts **6a** and **6b**, yielded the corresponding adducts **7a** and **7b** in moderate to good yields. In the reaction of C_{60} with **5b** the adduct **7b** was accompanied by a minor fraction corresponding to 2:1 adducts (two pyrimidone *o*-quinodimethanes added to one fullerene molecule), as indicated by its mass spectrum (M+H = 1021).



5a, R= H
5b, R= CH_3

7a, R= H
7b, R= CH_3

Adduct **7b** was fully characterized by ^1H and ^{13}C NMR, MS and IR. All the spectra are consistent with the proposed structure. However, because of its very low solubility in most solvents, adduct **7a** was characterized

by ^{13}C CP/MAS NMR, MS and IR spectroscopies. The ^{13}C CP/MAS NMR spectrum (figure 1) clearly shows the signals corresponding to the CH_3 group (22.5 ppm), the two CH_2 groups (36.9 and 46.3 ppm), the bridgehead fullerene carbons (65.0 ppm), the carbon 4a of the pyrimidone ring (119.5 ppm), the fullerene carbons (135.3-155.8 ppm) and the other three carbons of the pyrimidine ring (163.0 ppm). Again, this spectrum is totally compatible with the solution ^{13}C NMR spectrum of the adduct **7b** (see experimental). By comparison of the two spectra, it becomes very easy to identify the peak corresponding to the *N*-CH_3 group in compound **7b** (31.3 ppm).

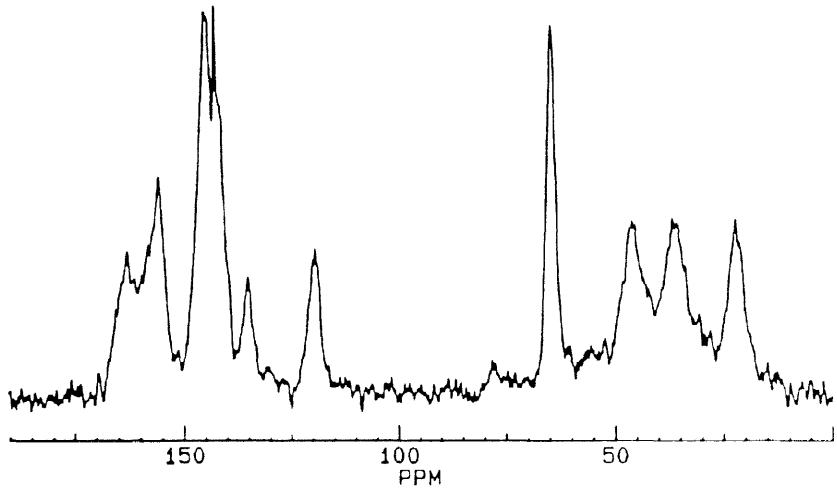


Figure 1- ^{13}C CP/MAS NMR spectrum of the pyrimidone derivative **7a**.

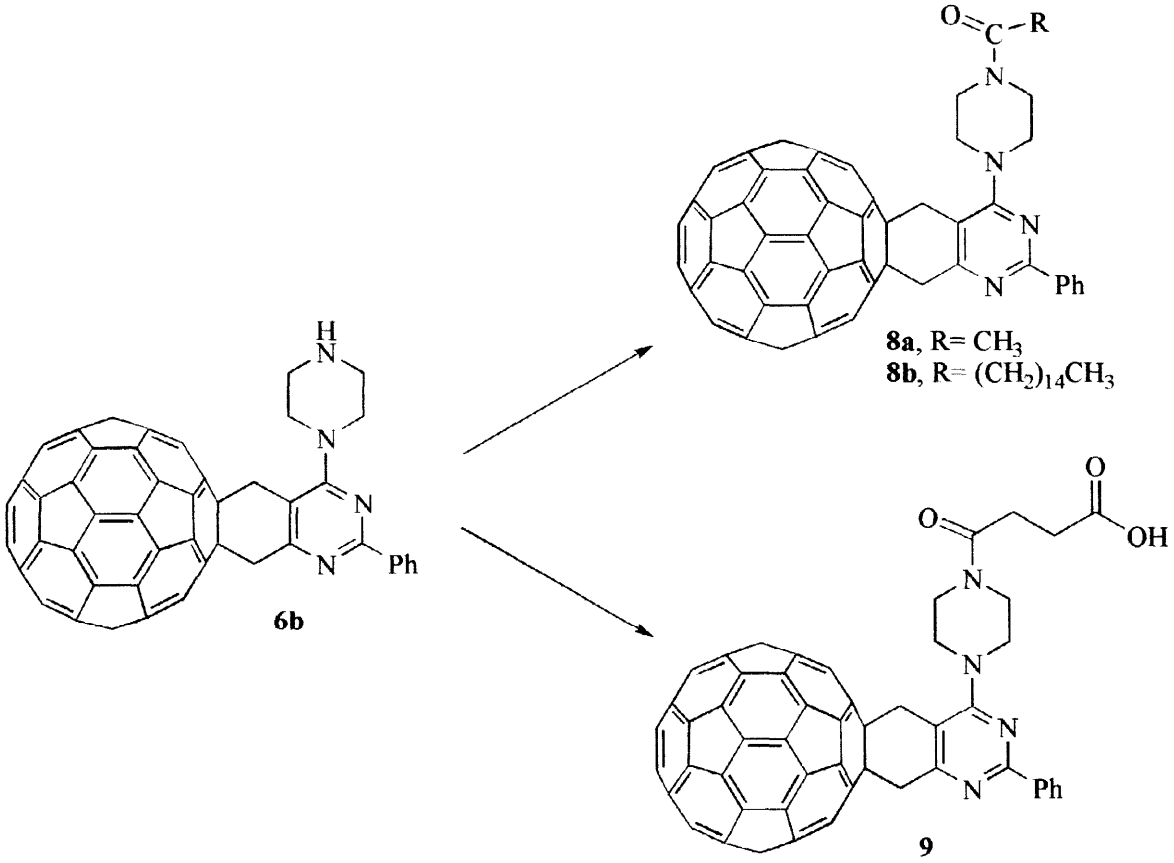
2.2- Synthesis of hydrophobic and hydrophilic fullerene derivatives

Compound **6b** has the synthetically useful amine functionality. Hence it was decided to explore this feature to transform it into other fullerene derivatives with different solubility paterns.

The reaction of adduct **6b** with acetic anhydride, in pyridine, yielded its *N*-acetyl derivative **8a**. This compound, which is very soluble in chloroform, was characterized by ^1H and ^{13}C NMR and MS. It is interesting to note that the ^{13}C NMR spectrum of compound **8a** shows nine signals corresponding to nine sp^3 carbons. This means that the four carbon atoms of the piperazinyl group are not magnetically equivalent. This effect (not observed in sulfone **4b** lacking the acetyl group) is probably due to the restricted rotation of the acetyl group about the C-N bond (a phenomenon common to *N,N*-disubstituted amides).[26] In a similar reaction, compound **6b** was transformed into its *N*-palmitoyl derivative **8b** by reaction with palmitoyl chloride. As expected, compound **8b** is very soluble in solvents such as dichloromethane or chloroform.

The reaction of compound **6b** with cyclic anhydrides was expected to give water soluble fullerene derivatives. It was disappointing to find that compound **9**, obtained by reaction of compound **6b** with succinic anhydride, is insoluble in water or in aqueous sodium hydroxide solutions; the presence of only one carboxylic group is not enough to allow its solubilization in aqueous solutions. The IR spectrum of compound **9** shows

clearly the peaks corresponding to the absorptions of the carboxylic (1716 cm^{-1}) and the amide (1625 cm^{-1}) groups.

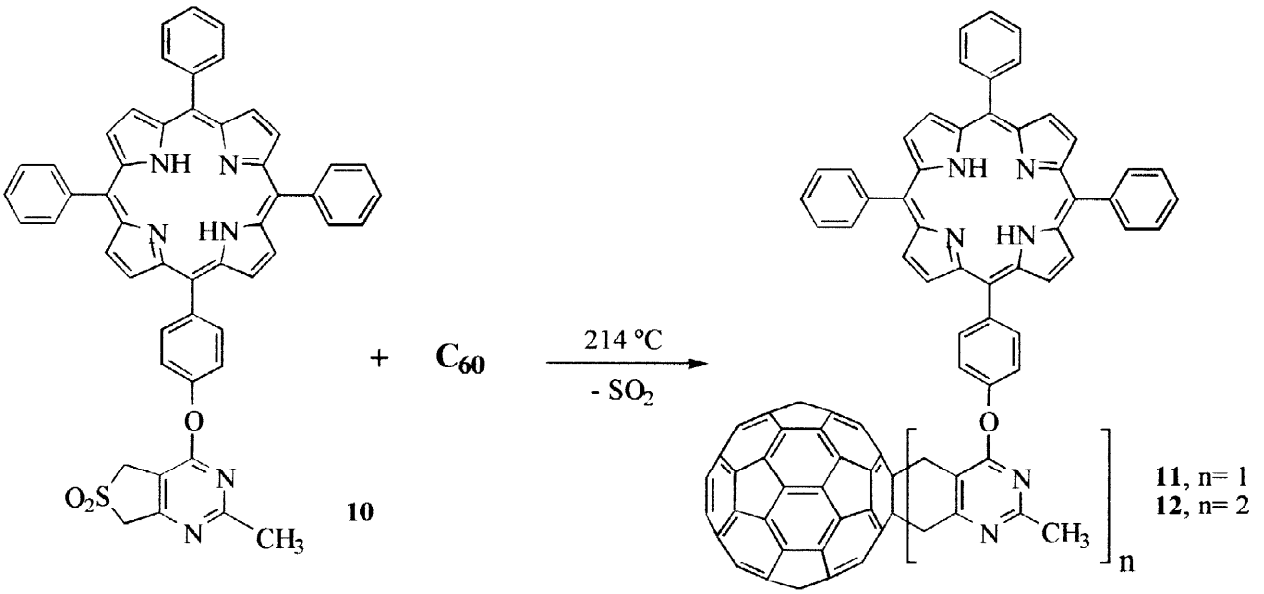


2.3- Synthesis of a porphyrin-quinazoline-fullerene triad

Recently, we have described the synthesis of the porphyrinpyrimidine fused 3-sulfolene **10** and its use in the synthesis of novel derivatives of *meso*-tetraphenylporphyrin.[27] The extrusion of sulfur dioxide from this porphyrin derivative **10** in the presence of [60]fullerene was expected to yield the new porphyrin-quinazoline-fullerene triad **11**. In the event, we found that, in fact, **10** can be successfully employed to the functionalization of C_{60}.

When porphyrin **10** and C_{60} were heated in refluxing 1,2,4-trichlorobenzene, two fractions, corresponding to new compounds, were obtained after chromatography (column and preparative TLC). The less polar one (shown by TLC and NMR to be only one compound) was obtained in 60% yield. Mass spectrum (M+H = 1469; M+2H = 1470) and the detailed analysis of the ^{1}H and ^{13}C NMR spectra, allowed us to confirm that we were in the presence of the novel 1:1 mono-adduct **11**. The ^{1}H NMR spectrum, in addition to the aromatic protons due to the porphyrinic ring, revealed the presence of one singlet at δ 2.81 ppm, which was assigned to the methyl

protons of the pyrimidine ring, and two singlets at δ 4.52 and 4.63 ppm corresponding to the four methylene protons. Besides the multitude of signals between 121.8 and 153.6 ppm (due to the presence of the porphyrin and fullerene carbons), the ^{13}C NMR spectrum showed resonances at 22.3, 42.3 (assigned, respectively, to the methyl and methylene carbons) and δ 64.3 ppm (bridgehead fullerene carbons).



The analysis of the other fraction by MS showed parent ions (M+H = 2217) which suggests the presence of the 2:1 adducts **12**. The formation of this type of adducts was confirmed by the reaction of the monoadduct **11** with 1.1 equivalents of **10**, in refluxing 1,2,4-trichlorobenzene; once again these type of compounds were obtained. It was observed by TLC that this fraction is constituted by several compounds with very similar R_f. These are, presumably, isomeric bisadducts;[28] no attempts were made to separate them.

3- EXPERIMENTAL

^1H and ^{13}C solution NMR spectra were recorded on a Bruker AMX 300 spectrometer. $CDCl_3$ or $CS_2/CDCl_3$ was used as solvent and TMS as internal reference. The coupling constants are given in Hz. ^1H-^{13}C Cross-polarization magic-angle spinning (CP/MAS) NMR spectra were recorded at 100.62 MHz on a Bruker MSL 400P spectrometer. The 7 mm double-bearing rotors were spun in air at 9.0 and 10.0 kHz. Contact times of 2 and 5 ms and recycle delays of 8s were used. Chemical shifts are quoted in ppm from (external) TMS. Mass spectra were recorded on a VG AutoSpec-Q instrument. The IR spectra were recorded on a Mattson 7020 Galaxy FTIR spectrometer. The UV-Vis spectra were recorded on a Hitachi U-2000 spectrophotometer. Melting points were determined with a Reichert Thermovar electric apparatus and are uncorrected.

Sulfone **4b** was obtained by the reaction of 4-chloro-2-phenyl-5,7-dihydrothieno[3,4-*d*]pyrimidine 6,6-dioxide (**4**, X= Cl) with piperazine following the procedure described in [22, 23]. Yield = 98%; **m.p.** = 225-226 °C; **^{1}H NMR** (300 MHz, $CDCl_3$) δ= 3.0 (t, 4H), 3.67 (t, 4H), 4.36 (s, 2H), 4.38 (s, 2H), 7.45-7.48 (m, 3H), 8.32-8.35 (m, 2H); **^{13}C NMR** (75 MHz, $CDCl_3$), δ= 46.0, 47.6, 56.6, 57.0, 106.2, 128.1, 128.4, 130.9, 137.2, 160.0, 160.3, 163.5; **MS** (EI^+) m/z (rel.int.) 330 (M+, 4%), 262 (60), 224 (13), 211 (27), 210 (30), 198 (36), 181 (18), 104 (100), 85 (19), 77 (35), 69 (29)

Adduct **6a**: C_{60} (72 mg; 0.1 mmol) and pyrimidine **4a** (28 mg; 0.1 mmol) were heated in refluxing 1,2,4-trichlorobenzene (5 ml), under nitrogen atmosphere, for 3 hours. After cooling to room temperature, the mixture was applied to the top of a silica column; the trichlorobenzene and the unreacted C_{60} were eluted with toluene and the adduct was then eluted with chloroform. Yield = 77%; **m.p.** > 320 °C; **^{1}H NMR** (300 MHz, CS_2/DMSO-d_6) δ= 4.23 (s, 3H, OCH_3), 4.66 (s, 2H, CH_2), 4.77 (s, 2H, CH_2), 7.38-7.44 (m, 3H, ArH), 8.53-8.53 (m, 2H, ArH); **^{13}C NMR** (75 MHz, CS_2/DMSO) δ= 36.1, 45.8, 53.4, 64.6, 64.7, 114.2, 128.0, 128.1, 190.3, 135.1, 135.2, 137.0, 139.7, 141.17, 141.21, 141.6, 141.7, 142.1, 142.6, 144.16, 144.19, 144.8, 144.9, 145.0, 145.1, 145.3, 145.7, 146.0, 147.1, 155.8, 162.2, 165.3, 166.5; **MS** (LSIMS; NBA) [M + H] = 933, [C_{60}] = 720

Adduct **6b**: Sulfone **4b** (37 mg; 0.11 mmol) and C_{60} (72 mg; 0.10 mmol) were heated in refluxing 1,2,4-trichlorobenzene (5 ml), under nitrogen atmosphere, for 3 hours. After cooling to room temperature, the adduct was precipitated by the addition of hexane. The solid was filtered, washed with hexane and refluxed with chloroform. After cooling to room temperature, the brown solid was filtered and dried (94.4 mg; 95%). **m.p.** > 320 °C; **^{13}C CP/MAS NMR** described in the text; **IR** ν_{max} (KBr) 1702, 1556, 1400, 1226, 1041, 759, 703, 669, 649, 526 cm^{-1}.

Adduct **7a**: Obtained from the reaction of C_{60} with pyrimidone **5a** following a procedure similar to the one described for the synthesis of adduct **6b**. Yield = 82%; **m.p.** > 320 °C; **^{13}C CP/MAS NMR** described in the text; **MS** (LSIMS; NBA) [M + H] = 857, [C_{60}] = 720; **IR** ν_{max} (KBr) 2360, 2343, 1654, 1598, 1567, 1427, 1110, 748, 669, 617, 574, 526 cm^{-1}.

Adduct **7b**: Obtained from the reaction of C_{60} with pyrimidone **5b** following a procedure similar to the one described for the synthesis of adduct **6a**. Yield = 52%; **m.p.** > 320 °C; **^{1}H NMR** (300 MHz, CS_2/$CDCl_3$) δ= 2.72 (s, 3H), 3.72 (s, 3H), 4.47 (s, 2H), 4.51 (s, 2H); **^{13}C NMR** (75 MHz, CS_2/$CDCl_3$) δ= 23.4, 31.3, 36.8, 45.9, 64.88, 64.91, 119.0, 135.1, 135.4, 139.9, 140.0, 141.40, 141.44, 141.8, 141.9, 142.3, 142.9, 144.3, 144.5, 144.8, 145.1, 145.2, 145.3, 145.5, 146.0, 146.2, 146.3, 147.3, 147.4, 155.6, 155.8, 158.4, 160.0, 160.7; **MS** (LSIMS; NBA) [M + H] = 871, [C_{60}] = 720; **IR** ν_{max} (KBr) 2360, 2341, 1666, 1540, 1428, 669, 526 cm^{-1}.

Adduct **8a**: A suspension of adduct **6b** (11 mg; 0.011 mmol) in acetic anhydride (2 ml) and pyridine (0.5 ml), under N_2, was stired for one hour at room temperature and then for another hour at 80 °C. After cooling to room temperature, the reaction mixture was added to water and acidified (pH= 4) with 20% HCl. The mixture was extracted with chloroform (3 x 20 ml) and the organic fraction was washed with a saturated solution of $NaHCO_3$ (2 x 15 ml). The organic extract was dried (Na_2SO_4), the solvent was evaporated and the residue was purified by preparative TLC. **^{1}H NMR** (300 MHz, $CDCl_3$) δ= 2.20 (s, 3H, CH_3), 3.78-3.88 (m, 8H, piperazinyl), 4.66-4.85 (m, 4H, CH_2); 7.55-7.59 (m, 3H, C_6H_5), 8.60-8.64 (m, 2H, C_6H_5); **^{13}C NMR** (75 MHz, $CDCl_3$) δ= 21.5, 40.3, 41.2, 45.9, 46.9, 48.6, 49.7, 64.9, 65.3, 116.0, 128.3, 128.5, 130.7, 137.9, 140.2, 143.3, 141.7, 141.8, 142.0, 142.1, 142.3, 142.6, 142.7, 143.2, 144.6, 144.8, 145.5, 145.6, 146.3, 146.5, 146.6, 155.9, 162.5, 163.6, 167.1, 169.4; **MS** (LSIMS; NBA) [M + H] = 1029, [C_{60}] = 720.

Adduct **8b**: Excess palmitoyl chloride (~ 20 equiv.) was added to a suspension of adduct **6b** (17 mg; 0.017 mmol) in dry pyridine (4 ml). The mixture was stired, under N_2, during four hours at room temperature and then for another hour at 50 °C. The pyridine was evaporated under reduced pressure and the residue was purified by preparative TLC (chloroform as eluent). The adduct (10 mg; 48%) was crystalized from chloroform/ petroleum ether. **m. p.**= 144-145 °C; **^{1}H NMR** (300 MHz, $CDCl_3$) δ= 0.88 (t, 3H, $(CH_2)_{13}\underline{CH_3}$), 1.25-1.67 (m, 26H, $(\underline{CH_2})_{13}CH_3$), 2.04 (t, 2H, $COCH_2$), 3.82-3.86 (m, 8H, piperazinyl), 4.64-4.85 (m, 4H, CH_2); 7.52-7.55 (m, 3H, C_6H_5), 8.58-8.61 (m, 2H, C_6H_5); **^{13}C NMR** (75 MHz, $CDCl_3$) δ= 14.1, 22.7, 25.4, 29.35, 29.46, 29.53, 29.7, 31.9, 33.4, 40.4, 41.3, 45.2, 46.9, 48.7, 49.8, 64.9, 65.3, 115.9, 128.3, 128.5, 130.6, 138.0, 140.2, 140.3, 141.7, 142.05, 142.10, 142.15, 142.6, 142.7, 143.2, 144.6, 144.8, 145.5, 146.3, 146.5, 146.6, 147.7, 148.8, 155.9, 162.5, 163.6, 167.1, 172.1; **MS** (LSIMS; NBA) [M + H] = 1226, [C_{60}] = 720.

Adduct **9**: Succinic anhydride (12 mg; 6 equiv.) was added to a suspension of adduct **6b** (20 mg; 0.02 mmol) in chlorobenzene (5 ml). The mixture was stired, under N_2, during two hours at 80 °C. On cooling to r.t., a brown solid was formed. It was filtered, refluxed in chlorobenzene, filtered once again, and washed with hexane. The solid was dried (17 mg; 77%) and characterized by m.p. and IR. **m.p.** > 300 °C; **IR** ν_{max} (KBr) 1716, 1625, 1556, 1401, 1230, 1166, 1041, 771, 701, 647, 526 cm^{-1}.

Adducts **11** and **12**: porphyrin **10** [27] (75 mg) and C_{60} (85 mg, 1.3 equivalents) were heated in refluxing 1,2,4-trichlorobenzene (5 ml), under nitrogen atmosphere, for 4 hours. After cooling to room temperature, the mixture was applied to the top of a column of silica; the trichlorobenzene and the unconsumed C_{60} were eluted with petroleum ether and the adducts were then eluted with chloroform. The adducts were separated by preparative TLC. Spectroscopic data for **11**: **m.p.** > 300 °C; **^{1}H NMR** (300 MHz, $CDCl_3$) δ= -2.92 (s, 2H, NH), 2.81 (s, 3H, CH_3), 4.52 (s, 2H, CH_2), 4.63 (s, 2H, CH_2), 7.58-7.72 (m, 11 H, phenyl-*m*- and *p*-H),

8.12-8.22 (m, 8H, phenyl-*o*-H), 8.75-8.86 (m, 8H, porphyrin β-H); **^{13}C NMR** (75 MHz, $CDCl_3/CF_3CO_2H$) δ= 22.3, 42.3, 64.3, 121.8, 123.9, 124.3, 128.8, 129.5, 129.8, 131.0, 135.5, 138.4, 139.0, 140.7, 141.8, 141.9, 142.1, 142.2, 142.4, 143.0, 143.4, 144.2, 144.5, 144.7, 144.8, 145.3, 145.7, 145.8, 146.0, 146.2, 146.6, 146.9, 148.1, 152.9, 153.6; **MS** (FAB^+, $CDCl_3/CF_3CO_2H$) 1469 $(M+H)^+$, 1470 $(M+2H)^+$; **UV-Vis** (*o*-dichlorobenzene) λ_{max} (log ε) 422 (5.60), 516 (4.26), 551 (3.98), 592 (3.75), 649 (3.68) nm.

Acknowledgements: Thanks are due to JNICT/"Fundação para a Ciência e a Tecnologia", Lisbon, for funding the Research Unit N° 62/94

REFERENCES AND NOTES

1. Jensen, A. W.; Wilson, S. R.; Schuster, D. I.; *Bioorg. Med. Chem.*, **1996**, *4*, 767-779.
2. Nakamura, E.; Tokuyama, H.; Yamago, S.; Shiraki, T.; Sugiura, Y. *Bull. Chem. Soc. Japan*, **1996**, *69*, 2143-2151 and references cited therein.
3. Liddell, P.; Sumida, J.; Macpherson, A.; Noss, L.; Seely, G.; Clark, K.; Moore, A.; Moore, T.; Gust, D. *Photochem. Photobiol.*, **1994**, *60*, 537-541.
4. Imahori, H.; Hagiwara, K.; Akiyama, T.; Taniguchi, S.; Okada, T.; Sakata, Y. *Chemistry Lett.*, **1995**, 265-266.
5. Drovetskaya, T.; Reed, C.; Boyd, P. *Tetrahedron Lett.*, **1995**, *36*, 7971-7974.
6. Imahori, H.; Sakata, Y. *Chemistry Lett.*, **1996**, 199-200.
7. Akiyama, T.; Imahori, H.; Ajawakom, A; Sakata, Y. *Chemistry Lett.*, **1996**, 907-908.
8. Ranasinghe, M.; Oliver, A.; Rothenfluh, D.; Salek, A.; Paddon-Row, M. *Tetrahedron Lett.*, **1996**, *37*, 4797-4800.
9. Imahory, H.; Hagiwara, K.; Aoki, M.; Akiyama, T.; Taniguchi, S.; Okada, T.; Shirakawa, M.; Sakata, Y. *J. Am. Chem. Soc.*, **1996**, *118*, 11771-11782.
10. Kuciauskas, D.; Lin, S.; Seeley, G.; Moore, T.; Gust, D.; Drovetskaya, T.; Reed, C.; Boyd, P. *J. Phys. Chem.*, **1996**, *100*, 15926-15932.
11. Liddell, P.; Kuciauskas, D.; Sumida, J.; Nash, B.; Nguyen, D.; Moore, A.; Moore, T.; Gust, D. *J. Am. Chem. Soc.*, **1997**, *119*, 1400-1405.
12. Sun, Y.; Drovetskaya, T.; Bolskar, R.; Bau, R.; Boyd, P.; Reed, C. *J. Org. Chem.*, **1997**, *62*, 3642-3649.
13. Baran, P.; Monaco, R.; Khan, A.; Schuster, D.; Wilson, S. *J. Am. Chem. Soc.*, **1997**, *119*, 8363-8364.
14. Safonov, I.; Baran, P.; Schuster, D. *Tetrahedron Lett.*, **1997**, *38*, 8133-8136.
15. Imahory, H.; Yamada, K.; Hasegawa, M.; Taniguchi, S.; Okada, T.; Sakata, Y. *Angew. Chem. Int. Ed. Ingl.*, **1997**, *36*, 2626-2629.
16. Tomé, A.; Enes, R.; Cavaleiro, J.; Elguero, J. *Tetrahedron Lett.*, **1997**, *38*, 2557-2560.
17. Eguchi, S.; Ohno, M.; Kojima, S.; Koide, N.; Yashiro, A.; Shirakawa, Y.; Ishida, H. *Fullerene Sci. Technol.*, **1996**, *4*, 303-327.

18. Fernández-Paniagua, U. M.; Illescas, B. M.; Martín, N.; Seoane, C. *J. Chem. Soc., Perkin Trans. 1*, **1996**, 1077-1079.

19. Fernández-Paniagua, U. M.; Illescas, B. M.; Martín, N.; Seoane, C.; Cruz, P.; Hoz, A.; Langa, F. *J. Org. Chem.*, **1997**, *62*, 3705-3710.

20. Ohno, M.; Koide, N.; Sato, H.; Eguchi, S. *Tetrahedron*, **1997**, *53*, 9075-9086.

21. Herrera, A.; Martínez, R.; González, B.; Illescas, B.; Martín, N.; Seoane, C. *Tetrahedron Lett.*, **1997**, *38*, 4873-4876.

22. Tomé, A. C.; Cavaleiro, J. A. S.; Storr, R. C. *Tetrahedron*, **1996**, *52*, 1735-1746.

23. Tomé, A. C.; Cavaleiro, J. A. S.; Storr, R. C. *Tetrahedron Lett.*, **1993**, *34*, 6639-6642.

24. Tomé, A. C.; Cavaleiro, J. A. S.; Storr, R. C. *Tetrahedron*, **1996**, *52*, 1723-1734.

25. Tomé, A. C.; O'Neill, P. M.; Cavaleiro, J. A. S.; Storr, R. C. *Synlett*, **1993**, 347-348.

26. Stothers, J. B. "Carbon-13 NMR Spectroscopy", Academic Press, New York, 1972, pp. 427.

27. Tomé, J. P.; Tomé, A. C.; Neves, M. G.; Cavaleiro, J. C. *Tetrahedron Lett.*, **1997**, *38*, 2753-2756.

28. Due to the fact that the *o*-quinodimethane generated from **10** is an asymmetric diene, the formation of 16 bisadducts **12** is theoretically possible (considering that the additions take place exclusively at 6-6 ring double bonds).