Central European Science Journals
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Central European Journal of Chemistry
Central European Science Journals
CEJC 3(4) 2005 658–667

A convenient synthesis of long-chain 4-substituted benzyloxycarbonyl alkanethiols for the formation of self assembled monolayers on metal substrates*

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Received 11 March 2005; accepted 13 June 2005

Abstract: New 4-substituted benzyl esters of 16-mercaptohexadecanoic acid were prepared by developing a practicable synthetic procedure and using readily available starting materials. The compounds synthesized have been characterized by NMR, MS, IR spectra and elemental analysis. The mercapto derivatives are precursors for the formation of self-assembled monolayers on metal substrates.

Keywords: Alkanethiols, hexadecanoic acid, esterification, N-acylurea, self-assembled monolayers (SAM)

1 Introduction

Long-chain alkanethiols and disulfides are well known to self-assemble and form ordered monomolecular films on noble metal surfaces [1]. The growing interest which these self-assembled monolayers (SAM) have attracted during the last two decades is provoked by the diverse applications they have found as model systems in physics, chemistry and biology as well as routine applications in corrosion research and nanolithography [2,3]. Most recently they were tested as building blocks in fabrication of biochips [4], opto-electronic devices [5] and sensors [6,7].

* Dedicated to Professor Dr. Manfred Hesse on the occasion of his 70^{th} birthday

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SAMs are generally composed by three basic constituents: a head group which is largely a thiol group that binds to the metal surface, a terminal group which forms the outer film surface and a spacer which is typically a carbon chain disposed between the head and terminal groups. By varying mostly the terminal group and the length and type of the spacer, one can tailor monolayers with specific properties.

While the prevailing part of the SAMs studied so far were n-alkanethiols, more attention was recently paid to different aromatic thiols, given their potential application in molecular electronics [8]. Characterization of model aryl-terminated alkanethiols deposited on metal surfaces is significant to rationalize the structure-determining forces that cause different orientation of SAMs, entirely built up by aromatic thiols from their aliphatic analogues [9, 10].

In attempts to design suitable model compounds, various synthetic strategies have been applied so far for preparation of terminally functionalized long-chain alkanethiols [11]. In most cases, the terminal aryl substitution was achieved via C-C or C-O bonding of the aryl group to the chain [11, 12]. To our knowledge there are a few examples of preparation and use of SAM of aliphatic esters of a long-chain mercaptoalkanoic acid [13-17] and only two examples of substituted benzyl (including triphenylmethyl) esters of mercaptoalcanoic acids [12, 18].

In the present paper we report on the synthesis of a set of 4-substituted benzyl esters of the 16-mercaptohexadecanoic acid developing a practicable procedure and using readily available starting materials. The formation of SAMs fabricated from these substances on different metal substrates and their characterization will be published elsewhere.

2 Experimental

The organic solvents were distilled prior to use. Ether was distilled over sodium/benzophenone. Acetone was dried over K_2CO_3 distilled and kept over molecular sieve. Thin layer chromatography (TLC): aluminium sheets precoated with silica gel 60 F_{254} (***Merck***). Flash chromatography (FC): silica gel 60 (0.040-0.063 mm, ***Merck***). Melting points: BOETIUS, type PHMK05. FT-IR spectra (KBr disk): ***Bruker IFS*** 113v, ν in cm^{-1}. ^1H and ^{13}C NMR Spectra (300 K): ***Bruker Avance DRX-250*** spectrometer; $CDCl_3$ solution; δ in ppm relative to tetramethylsilane (TMS, δ=0 ppm); J in Hz; C-multiplicities were assigned by DEPT techniques; the assignments marked with asterisks (*) are tentative. EI-MS (70 eV): ***Hewlett Packard*** 6890/5973; fragmentation in m/z with relative intensities (%) in parentheses. Elemental analyses were performed by the Microanalytical Service Laboratory of the Institute of Organic Chemistry.

2.1 General procedure **(GP1)** for the esterification of 16-bromohexadecanoic acid **(1)**

In a 50 ml two-necked flask, equipped with an electro-magnetic stirrer and a drying tube were dissolved 16-bromohexadecanoic acid **1**, the corresponding benzyl alcohol **2** and

4-dimethylaminopyridine (DMAP) in dry ether under argon atmosphere. Dicyclohexylcarbodiimide (DCC) was added in a few portions in solid state and the mixture was stirred at room temperature until the esterification was complete (monitored by TLC). N,N-dicyclohexylurea precipitated during the reaction was filtered, the filtrate was washed with 2N HCl, 5 % aq. $NaHCO_3$ and water (2 x 10 ml). The organic phase was dried over anhydrous Na_2SO_4 and the solvent evaporated in vacuum, to give crude product.

2.1.1 4-Metoxybenzyl 16-bromohexadecanoate **(3a)**

Following **GP1**, **3a** was prepared from **1** (0.300 g, 0.89 mmol), **2a** (0.12 ml, 0.98 mmol) and DMAP (0.055 g, 0.45 mmol) in 10 ml of dry ether. DCC (0.202 g, 0.98 mmol) was added in portions within 20 min. After stirring for 4 hours the mixture was worked up. The crude product was purified by flash chromatography (∅=17 mm, h=490 mm, 40 g silica gel, petroleum ether/Et_2O=5:1) to give 0.303 g (75 %) **3a** as a colorless solid, m.p. 49-50 °C (petroleum ether) and 0.029 g (6 %) of 1-(16-bromohexadecanoyl)-1,3-dicyclohexylurea **4** as a colorless solid, m.p. 100-101 °(ethanol).

Data for **3a:** IR: 2959 (shoulder, $\nu_{as}CH_3$), 2916 (vs, $\nu_{as}CH_2$), 2851 (s, ν_sCH_2), 1731 (vs, νC=O), 1615 (m, Ph), 1516 (s, Ph), 1473, 1454 (δCH_2), 1466 (shoulder, $\delta_{as}CH_3$), 1441 (δ_sCH_3), 1385 (ωCH_2), 1262 and 1250 (doublet, νPh-OCH_3), 1160 (s, νCO-C). ^{1}H NMR: 7.32-7.27 (m, 2H, Ph), 6.91-6.85 (m, 2H, Ph), 5.04 (s, 2H, H-C(17)), 3.80 (s, 3H, CH_3), 3.40 (t, 2H, J=6.8, H-C(16)), 2.32 (t, 2H, J=7.5, H-C(2)), 1.91-1.79 (m, 2H, CH_2), 1.67-1.56 (m, 2H, CH_2), 1.45-1.25 (m, 22H, 11CH_2). ^{13}C NMR: 173.69 (s, C(1)), 159.50 (s, C(21)), 129.95 (d, 2CH, Ph), 128.21 (s, C(18)), 113.84 (d, 2CH, Ph), 65.80 (t, C(17)), 55.19 (q, CH_3), 34.30 (t, CH_2), 33.98 (t, CH_2), 32.78 (t, CH_2), 29.55 (t, 3CH_2), 29.51 (t, CH_2), 29.48 (t, CH_2), 29.38 (t, 2CH_2), 29.19 (t, CH_2), 29.06 (t, CH_2), 28.71 (t, CH_2), 28.12 (t, CH_2), 24.89 (t, CH_2). MS: for M^+ 456 (7.8) and 454 (8), 289 (25), 261 (19), 190 (21), 138 (17), 121 ($H_3COC_6H_4CH_2^+$, 100), 111 (32), 97 (49), 83 (45), 69 (28), 55 (32), 41 (25). Anal. calc. for $C_{24}H_{39}BrO_3$ (455.47): C, 63.29; H, 8.63; Br, 17.54; found: C, 63.33; H, 8.74; Br, 17.83.

Data for **4**: IR: 3343 (m, νNH, not associated), 2921 (vs, $\nu_{as}CH_2$), 2847 (s, ν_sCH_2), 1684 (s, νCON, amide I), 1656 (vs, νCONH, amide I), 1523 (s, δNHCO), 1467 (w, δCH_2), 1453 (w, δCH_2, cyclohexane ring), 1374 (w, νCONH, amide III), 1341 (w, δCH). ^{1}H NMR (328 K): 7.00 (1H, NH), 3.94-3.84 (m, 1H, CH), 3.69-3.65 (m, 1H, CH), 3.38 (t, 2H, J=6.8, H-C(16′)), 2.39 (t, 2H, J=7.5, H-C(2′)), 1.98-1.57 (m, 16H, 8CH_2), 1.46-1.11 (m, 30H, 15CH_2). ^{13}C NMR (328 K): 173.95 (s, C(1′)), 154.19 (s, C(2)), 56.18 (d, CH), 49.71 (d, CH), 35.92 (t, CH_2), 33.68 (t, CH_2), 32.86 (t, CH_2), 32.76 (t, 2CH_2), 30.99 (t, 2CH_2), 29.57 (t, 2CH_2), 29.54 (t, 2CH_2), 29.47 (t, CH_2), 29.41 (t, CH_2), 29.38 (t, CH_2), 29.34 (t, CH_2), 29.26 (t, CH_2), 28.72 (t, CH_2), 28.16 (t, CH_2), 26.42 (t, 2CH_2), 25.56 (t, CH_2), 25.50 (t, CH_2), 25.38 (t, CH_2), 24.68 (t, 2CH_2). MS: for M^+ 542 (4.9) and 540 (5), 461 ([M-Br]$^+$, 77), 416 (26), 336 (55), 318 (7), 266 (15), 223 (25), 185 (15), 154 (20), 141 ($CH_3CONHC_6H_{11}^+$, 100), 98 (49), 83 (22), 69 (16), 55 (28), 41 (12).

2.1.2 4-Cyanobenzyl 16-bromohexadecanoate **(3b)**

Following **GP1**, **3b** was prepared from **1** (0.300 g, 0.89 mmol), **2b** (0.173 g, 1.30 mmol) and DMAP (0.055 g, 0.45 mmol) in 15 ml of dry ether. DCC (0.202 g, 0.98 mmol) was added in portions within 20 min. After stirring for 3 hours, the mixture was worked up. The crude product was purified by flash chromatography (∅=12 mm, h=520 mm, 25 g silica gel, petroleum ether/ether=5:1) to give 0.262 g (65 %) **3b** as a colorless solid, m.p. 65-66 °C (petroleum ether) and 0.093g (19 %) **4**.

3b: IR: 2916 (vs, $\nu_{as}CH_2$), 2849 (s, ν_sCH_2), 2230 (m, νCN), 1719 (vs, νC=O), 1612 (w, Ph), 1509 (w, Ph), 1474 and 1464 (doublet, δCH_2), 1190 and 1177 (doublet, νCO-O), 828 (γPh). ^{1}H NMR: 7.66-7.62 (m, 2H, Ph), 7.45-7.42 (m, 2H, Ph), 5.14 (s, 2H, H-C(17)), 3.39 (t, 2H, J=6.8, H-C(16)), 2.37 (t, 2H, J=7.4, H-C(2)), 1.89-1.77 (m, 2H, CH_2), 1.68-1.57 (m, 2H, CH_2), 1.43-1.23 (m, 22H, $11CH_2$). ^{13}C NMR: 173.26 (s, C(1)), 141.39 (s, C(18)), 132.26 (d, 2CH, Ph), 128.15 (d, 2CH, Ph), 118.47* (s, CN), 111.81* (s, C (21)), 64.72 (t, CH_2, C(17)), 34.06 (t, CH_2), 34.00 (t, CH_2), 32.74 (t, CH_2), 29.52 (t, $3CH_2$), 29.48 (t, CH_2), 29.44 (t, CH_2), 29.34 (t, $2CH_2$), 29.13 (t, CH_2), 29.00 (t, CH_2), 28.67 (t, CH_2), 28.07 (t, CH_2), 24.79 (t, CH_2). MS: for M^+ 451 (0.98) and 449 (1), 370 ($[M\text{-}Br]^+$, 33), 315 (20), 301 (11), 287 (10), 273 (8), 259 (5), 116 ($NCC_6H_4CH_2^+$, 100), 97 (15), 83 (15), 69 (18), 55 (22). Anal. calc. for $C_{24}H_{36}BrNO_2$ (450.45): C, 63.99; H, 8.06; Br, 17.74; N, 3.11; found: C, 63.85; H, 8.05; Br, 18.06; N, 3.02.

2.1.3 4-Nitrobenzyl 16-bromohexadecanoate **(3c)**

Following **GP1**, **3c** was prepared from **1** (0.400 g, 1.20 mmol), **2c** (0.219 g, 1.43 mmol) and DMAP (0.073 g, 0.6 mmol) in 12 ml of dry ether. DCC (0.272 g, 1.32 mmol) was added in a few portions for 35 min. After stirring for 3.5 hours, the mixture was worked up. The crude product was purified by flash chromatography (∅=17 mm, h=380 mm, 30 g silica gel, petroleum ether/ether=5:1) to give 0.313 g (56 %) **3c** as a colorless solid, m.p. 50-50.5 °C (petroleum ether).

IR: 2918 (vs, $\nu_{as}CH_2$), 2851 (s, ν_sCH_2), 1740 (vs, νC=O), 1608 (w, Ph), 1521 (vs, $\nu_{as}NO_2$), 1471, 1452 (m, δCH_2), 1348 (s, ν_sNO_2), 1150 (s, νCO-O), 836 (γPh). ^{1}H NMR: 8.23-8.18 (m, 2H, Ph), 7.53-7.47 (m, 2H, Ph), 5.19 (s, 2H, H-C(17)), 3.39 (t, 2H, J=6.9, H-C(16)), 2.38 (t, 2H, J=7.6, H-C(2)), 1.89-1.78 (m, 2H, CH_2), 1.70-1.58 (m, 2H, CH_2), 1.43-1.24 (m, 22H, $11CH_2$).^{13}C NMR: 173.26 (s, C(1)), 147.56* (s, C(18)), 143.39* (s, C(21)), 128.24 (d, 2CH, Ph), 123.69 (d, 2CH, Ph), 64.46 (t, CH_2, C(17)), 34.09 (t, CH_2), 34.01 (t, CH_2), 32.76 (t, CH_2), 29.54 (t, $3CH_2$), 29.50 (t, CH_2), 29.47 (t, CH_2), 29.36 (t, $2CH_2$), 29.15 (t, CH_2), 29.03 (t, CH_2), 28.70 (t, CH_2), 28.10 (t, CH_2), 24.82 (t, CH_2). MS: for M^+ 471 (0.29) and 469 (0.3), for $[M\text{-}NO]^+$ 441 (2.9) and 439 (3), for $[M\text{-}NO_2C_6H_4CH_2]^+$ 335 (13.6) and 333 (14), 317 (33), 297 (9), 178 (19), 137 (100), 121 (10). Anal. calc. for**:** $C_{23}H_{36}BrNO_4$ (470.44): C, 58.72; H, 7.71; N, 2.98; found: C, 58.94; H, 7.73; N, 3.05.

2.1.4 4-Chlorobenzyl 16-bromohexadecanoate **(3d)**

Following **GP1**, **3d** was prepared from **1** (0.500 g, 1.49 mmol), **2d** (0.255 g, 1.79 mmol) and DMAP (0.091 g, 0.74 mmol) in 20 ml of dry ether. DCC (0.338 g, 1.64 mmol) was added in portions for 15 min. After stirring for 3.5 hours, the mixture was worked up. The crude product was purified by flash chromatography: ∅=17 mm, h=380 mm, 32 g silica gel, petroleum ether/ether=20:1 to give 0.370 g **3d** (54 %), as a colorless solid, m.p. 48-49 °C (petroleum ether).

IR: 2916 (vs, $\nu_{as}CH_2$), 2850 (s, ν_sCH_2), 1734 (vs, νC=O), 1600 (w, Ph), 1491 (w, Ph), 1473, 1454 (m, δCH_2), 1159 (s, νCO-O). ^{1}H NMR: 7.31-7.27 (m, 4H, Ph), 5.07 (s, 2H, H-C(17)), 3.40 (t, 2H, J=6.9, H-C(16)), 2.34 (t, 2H, J=7.3, H-C(2)), 1.90-1.79 (m, 2H, CH_2), 1.68-1.57 (m, 2H, CH_2), 1.44-1.25 (m, 22H, $11CH_2$).^{13}C NMR: 173.50 (s, C(1)), 134.60* (s, C(18)), 133.98* (s, C(21)), 129.50 (d, 2CH, Ph), 128.66 (d, 2CH, Ph), 65,15 (t, CH_2, C(17)), 34.22 (t, CH_2), 34.01 (t, CH_2), 32.79 (t, CH_2), 29.57 (t, $3CH_2$), 29.52 (t, CH_2), 29.50 (t, CH_2), 29.39 (t, $2CH_2$), 29.19 (t, CH_2), 29.06 (t, CH_2), 28.73 (t, CH_2), 28.13 (t, CH_2), 24.88 (t, CH_2). MS: for M^+ 460 (3.9) and 458 (4), for $[M\text{-}H_2O]^+$ 442 (0.98) and 440 (1), for $[M\text{-}ClC_6H_4CH_2]^+$ 335 (8.7) and 333 (9), 317 (18), 299 (8), 297 (8), 125 ($ClC_6H_4CH_2^+$, 100), 111 (9), 97 (14), 83 (14), 69 (15), 55 (19), 41 (11). Anal.calc. for: $C_{23}H_{36}BrClO_2$ (459.89): C, 60.07; H, 7.89; Br, 17.37; Cl, 7.71; found: C, 60.18; H, 8.02; Br, 17.64; Cl, 7.84.

2.2 General procedure **(GP2)** for preparation of **5a-d**

A solution of the corresponding ester **3** (1 mmol) and thiourea (4 mmol) in dry acetone was refluxed under argon atmosphere for a period of 47-68 hours. The consummation of the bromoester was monitored by TLC. The solvent was evaporated in vacuum and a mixture of CH_2Cl_2/H_2O (2:1) and sodium pyrosulfite ($Na_2S_2O_5$, 1.8 mmol) was added. The mixture was stirred and refluxed for additional 3-10 h and monitored by TLC. The organic layer was separated, washed two times with water and dried over Na_2SO_4.

2.2.1 4-Metoxybenzyl 16-mercaptohexadecanoate **(5a)**

Following **GP2**, **3a** (0.155 g, 0.34 mmol) and thiourea (0.106 g, 1.40 mmol) were dissolved in 10 ml of dry acetone. The solution was stirred and refluxed for 51 hours. The solvent was evaporated and $Na_2S_2O_5$ (0.116 g, 0.61 mmol), 20 ml CH_2Cl_2, and 10 ml H_2O were added. The mixture was refluxed for 9 hours and worked up to give 0.123 g **5a** (89 %) as a colorless solid, m.p. 42-44 °C (ethanol).

IR: 2958 (w, $\nu_{as}CH_3$), 2916 (vs, $\nu_{as}CH_2$), 2850 (s, ν_sCH_2), 1733 (vs, νC=O), 1614 (m, Ph), 1515 (s, Ph), 1473, 1466 (shoulder, $\delta_{as}OCH_3$), 1452 (δCH_2), 1441 (δ_sOCH_3), 1385 (ωCH_2), 1263 and 1253 (doublet, νPh-OCH_3), 1159 (s, νCO-O). ^{1}H NMR: 7.30-7.27 (m, 2H, Ph), 6.91-6.86 (m, 2H, Ph), 5.04 (s, 2H, H-C(17)), 3.81 (s, 3H, CH_3), 2.52 (q, 2H, J=7.3, H-C(16)), 2.32 (t, 2H, J=7.5, H-C(2)), 1.63-1.55 (m, 5H, H-C(3), H-C(15), HS), 1.36-1.24 (m, 22H, $11CH_2$). ^{13}C NMR: 173.71 (s, C(1)), 159.47 (s, C(21)), 129.95 (d,

2CH, Ph), 128.17 (s, C(18)), 113.81 (d, 2CH, Ph), 65.78 (t, C(17)), 55.18 (q, CH_3), 34.29 (t, CH_2), 33.98 (t, CH_2), 29.57 (t, $3CH_2$), 29.51 (t, $2CH_2$), 29.45 (t, CH_2), 29.38 (t, CH_2), 29.18 (t, CH_2), 29.05 (t, CH_2), 29.02 (t, CH_2), 28.32 (t, CH_2), 24.88 (t, CH_2), 24.59 (t, CH_2). MS: 408 (M^+, 2), 153 (3), 138 (4), 121 ($H_3COC_6H_4CH_2^+$, 100), 109 (2), 91 (4), 69 (4), 55 (8), 41 (5). Anal. calc. for $C_{24}H_{40}O_3S$ (408.64): C, 70.54; H, 9.87; S, 7.85; found: C, 70.56; H, 9.86; S, 7.76.

2.2.2 4-Cyanobenzyl 16-mercaptohexadecanoate **(5b)**:

Following **GP2**, **3b** (0.261 g, 0.58 mmol) and thiourea (0.176 g, 2.32 mmol) were dissolved in 12 ml of dry acetone. The solution was stirred and refluxed for 47 hours. The solvent was evaporated and $Na_2S_2O_5$ (0.198 g, 1.04 mmol), 20 ml CH_2Cl_2, and 10 ml H_2O were added. The mixture was refluxed for 5 hours and worked up to give 0.215 g **5b** (92 %) as a colorless solid, m.p. 55-56 °C (ethanol).

IR: 2915 (vs, $\nu_{as}CH_2$), 2850 (s, ν_sCH_2), 2230 (m, $\nu C{\equiv}N$), 1723 (vs, $\nu C{=}O$), 1612 (w, Ph), 1510 (w, Ph), 1475 and 1463 (doublet, δCH_2), 1176 (s, νCO-O), 829 (γPh), 729 and 718 (doublet, ρCH_2). ^{1}H MNR: 7.68-7.64 (m, 2H, Ph), 7.46-7.43 (m, 2H, Ph), 5.15 (s, 2H, H-C(17)), 2.52 (q, 2H, J = 7.3, H-C(16)), 2.38 (t, 2H, J=7.5, H-C(2)), 1.67-1.54 (m, 5H, H-C(3), H-C(15), HS), 1.42-1.24 (m, 22H, $11CH_2$). ^{13}C NMR: 173.24 (s, C(1)), 141.39 (s, C(18)), 132.25 (d, 2CH, Ph), 128.14 (d, 2CH, Ph), 118.45* (s, CN), 111.82* (s, C(21)), 64.72 (t, C(17)), 34.06 (t, CH_2), 33.94 (t, CH_2), 29.52 (t, $3CH_2$), 29.47 (t, $2CH_2$), 29.41 (t, CH_2), 29.34 (t, CH_2), 29.12 (t, CH_2), 29.00 (t, CH_2), 28.97 (t, CH_2), 28.28 (t, CH_2), 24.79 (t, CH_2), 24.56 (t, CH_2). MS: 403 (M^+, 11), 385 ([M-H_2O]$^+$, 9), 370 ([M-SH]$^+$, 17), 356 (15), 314 (7), 269 (67), 241 (32), 151 (8), 133 (30), 116 ($NCC_6H_4CH_2^+$, 100), 101 (12), 87 (22), 69 (18), 55 (25), 41 (12). Anal. calc. for $C_{24}H_{37}NO_2S$ (403.62): C, 71.42; H, 9.24; N, 3.47; S, 7.94; found: C, 71.57; H, 9.21; N 3.39; S, 7.69.

2.2.3 4-Nitrobenzyl 16-mercaptohexadecanoate **(5c)**

Following **GP2**, **3c** (0.230 g, 0.49 mmol) and thiourea (0.151 g, 1.99 mmol) were dissolved in 20 ml of dry acetone. The mixture was stirred and refluxed for 68 hours. The solvent was evaporated and $Na_2S_2O_5$ (0.167 g, 0.88 mmol), 20 ml CH_2Cl_2, and 10 ml H_2O were added. The mixture was refluxed for 3 hours and worked up to give 0.146 g (70 %) **5c** as a colorless solid, m.p. 46-47 °C (ethanol).

IR: 2915 (vs, $\nu_{as}CH_2$), 2851 (s, ν_sCH_2), 2574 (w, νSH), 1741 (s, $\nu C{=}O$), 1606 (w, Ph), 1516 (vs, $\nu_{as}NO_2$), 1473, 1454 (δCH_2), 1354 (s, ν_sNO_2), 1156 (s, νCO-O), 716 (ρCH_2). ^{1}H NMR: 8.24-8.20 (m, 2H, Ph), 7.54-7.48 (m, 2H, Ph), 5.20 (s, 2H, H-C(17)), 2.52 (q, 2H, J=7.3, H-C(16)), 2.39 (t, 2H, J=7.6, H-C(2)), 1.71-1.50 (m, 5H, H-C(3), H-C(15), HS), 1.39-1.25 (m, 22H, $11CH_2$). ^{13}C NMR: 173.26 (s, C(1)), 147.54* (s, C(18)), 143.39* (s, C(21)), 128.24 (d, 2CH, Ph), 123.69 (d, 2CH, Ph), 64.46 (t, C(17)), 34.07 (t, CH_2), 33.98 (t, CH_2), 29.55 (t, $3CH_2$), 29.51 (t, $2CH_2$), 29.44 (t, CH_2), 29.36 (t, CH_2), 29.16 (t, CH_2), 29.03 (t, CH_2), 29.00 (t, CH_2), 28.30 (t, CH_2), 24.82 (t, CH_2), 24.59 (t, CH_2). MS: 423 (M^+, 0.2), 406 (1), 388 (2), 344 (6), 285 (5), 269 (78), 137 (100), 121 (28), 106 (19), 90 (11), 78 (11), 69 (13), 55 (18). Anal. calc. For $C_{23}H_{37}NO_4S$ (423.61): C, 65.21;

H, 8.80; N, 3.31; S, 7.57; found: C, 65.09; H, 8.88; N, 3.48; S, 7.74.

2.2.4 4-Chlorobenzyl 16-mercaptohexadecanoate **(5d)**

Following **GP2**, **3d** (0.221 g, 0.48 mmol) and thiourea (0.146 g, 1.92 mmol) were dissolved in 20 ml of dry acetone. The mixture was stirred and refluxed for 68 hours. The solvent was evaporated and $Na_2S_2O_5$ (0.164 g, 0.864 mmol), 20 ml CH_2Cl_2, and 10 ml water were added. The mixture was refluxed for 3 hours and worked up to give 0.178 g (90 %) **5d** as a pale yellow solid, m.p. 45-45.5°C (ethanol).

IR: 2916 (vs, $\nu_{as}CH_2$), 2850 (s, ν_sCH_2), 1737 (s, νC=O), 1600 (w, Ph), 1491 (w, Ph), 1473, 1450 (δCH_2), 1163 (m, νCO-O), 716 (ρCH_2). ^{1}H NMR: 7.35-7.27 (m, 4H, Ph), 5.07 (s, 2H, H-C(17)), 2.52 (q, 2H, J=7.3, H-C(16)), 2.34 (t, 2H, J=7.6, H-C(2)), 1.66-1.54 (m, 5H, H-C(3), H-C(15), HS), 1.4-1.25 (m, 22H, $11CH_2$). ^{13}C NMR: 173.49 (s, C(1)), 134.59* (s, C(18)), 133.96* (s, C(21)), 129.49 (d, 2CH, Ph), 128.64 (d, 2CH, Ph), 65.13 (t, C(17)), 34.20 (t, CH_2), 34.00 (t, CH_2), 29.57 (t, $3CH_2$), 29.52 (t, $2CH_2$), 29.46 (t, CH_2), 29.38 (t, CH_2), 29.18 (t, CH_2), 29.05 (t, CH_2), 29.02 (t, CH_2), 28.33 (t, CH_2), 24.86 (t, CH_2), 24.60 (t, CH_2). MS: 412 (M^+, 0.2), 377 ([M-Cl]$^+$, 22), 269 (90), 157 (21), 125 ($ClC_6H_4CH_2^+$, 100), 111 (2), 97 (4), 89 (8), 69 (8), 55 (14). Anal. calc. for: $C_{23}H_{37}ClO_2S$ (413.06): C, 66.88; H, 9.03; Cl, 8.58; S, 7.76; found: C, 67.04; H, 9.40; Cl, 8.32; S, 7.65.

3 Results and discussion

The initial synthetic strategy to prepare the desired long-chain alkanethiol compounds was directed to the synthesis of 4-substituted phenyl esters of the 16-hydroxylhexadecanoic acid. The esterification was achieved using dicyclohexyl carbodiimide (DCC) and the yields realized were good (between 60-70 %). However the following transformation of the OH-group of the synthesized esters into HS-group afforded condition drastic enough to destroy the esters. Therefore another synthetic approach has been chosen which is shown in Fig. 1 (the numbering of the C-atoms refers to the assignment of the NMR spectra).

Commercially available 16-bromohexadecanoic acid **1** was allowed to react with 4-substituted benzyl alcohols **2a-d** in dry diethyl ether using the DCC/DMAP (4-dimethylaminopyridine) reaction conditions [19, 20, 21]. It was necessary to carefully optimize the reaction conditions, since formation of substantial amounts of the byproduct **4** was observed. The optimization of the conditions for the preparation of **3a-d** was achieved by using the reaction of **1** and **2a** as shown in Table 1.

The yield of **3a** and the formation of the byproduct **4** strongly depend on the quantity of DMAP used. The best reaction conditions were those given in Entry 3 using 0.5 equivalent of DMAP and 1.1 equivalents of DCC per equivalent of **1** and they were consequently enforced to all other esterification reactions. The reaction runs smoothly if the reagent DCC is added slowly to the reaction mixture of **1**, **2** and DMAP (see experimental), which has also been recommended by others [19].

The byproduct **4** was isolated and characterized by spectral methods (NMR, MS, IR).

The accomplishment of a precise elemental analysis, however, failed due to non-removable impurities of unconverted **1**. Acylurea derivatives similar to **4** have been described and synthetically used [22]. The optimized reaction conditions allowed the preparation of compounds **3a-d** in yields between 54-75 % (see experimental part).

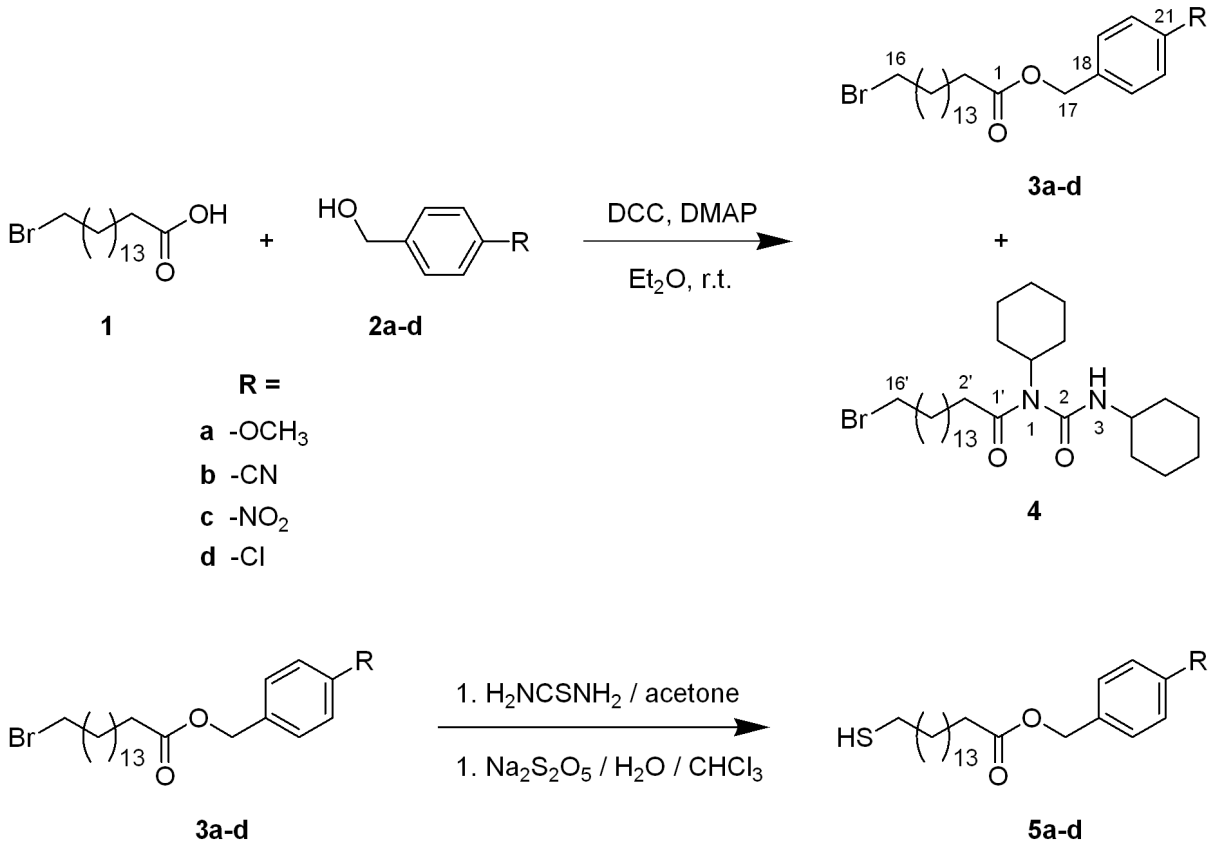

Fig. 1 Synthesis of compounds **3a-d** and **5a-d**.

Entry No	**1** eq	DCC eq	DMAP eq	Time [h]	**3a** %	**4** %	**1** %
1	1	1.1	0	24	3	26	*a)*
2	1	1.1	1	2	49	25	traces
3	1	1.1	0.5	4	75	6	traces
4	1	1.1	0.2	18	5	34	*a)*

[a] Mixture of **1** and **4** was isolated, in which the content of **1** has not been determined.

Table 1 Optimization of reaction conditions for preparation of compound **3a**.

The conversion of compounds **3a-d** into **5a-d** was carried out by refluxing **3** in dry acetone in presence of thiourea followed by hydrolytic work up with sodium pyrosulfite

[23] (Fig. 1). The yields of the isolated **5a-d** were high (70-92 %). The new compounds were characterized by means of ^{1}H and ^{13}C NMR, MS, IR and elemental analysis.

4 Conclusions

A simple and practicable procedure for synthesis of diverse long-chain 4-substituted benzyloxycarbonyl alkanethiols capable to self-assemble on noble metal surfaces is suggested. It is based on reaction of the commercially available 16-bromohexadecanoic acid with 4-substituted benzyl alcohols in the presence of dicyclohexylcarbodiimide (DCC) and 4-dimethylaminopyridine (DMAP). The formation of acylurea as byproduct is avoided by optimization of the reaction conditions. The conversion of the benzyl esters of 16-bromohexadecanoic acid into the corresponding 16-mercapto derivatives is carried out by using thiourea and subsequent hydrolytic work up with sodium pyrosulfite.

Acknowledgment

We are indebted to Dr. V. Dimitrov for the helpful discussions. The financial support by the Deutsche Forschungsgemeinschaft and the Bulgarian Academy of Sciences under a contract 436 BUL 113/127/0-1 as well as from the National Science Fund under a contract X-1315 is gratefully acknowledged.

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