Russian Journal of Applied Chemistry, Vol. 78, No. 4, 2005, pp. 623–627. Translated from Zhurnal Prikladnoi Khimii, Vol. 78, No. 4, 2005, pp. 629–633.

MACROMOLECULAR CHEMISTRY AND POLYMERIC MATERIALS

Use of an Acrylic Dendron-containing Monomer in the Synthesis of a Macroporous Polymeric Material

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Received July 26, 2004; in final form, December 2004

Abstract—A procedure was developed for preparing a monolithic macroporous material by photoinitiated copolymerization of glycidyl methacrylate, ethylene glycol dimethacrylate, and an acrylic comonomer containing a dendron with protected terminal amino groups. The macropore formation is provided by a blowing agent.

Dendrimers and superbranched polymers were synthesized in the late 1980s. Active efforts are made today to find applications for dendrimers. For this purpose, numerous modified dendrons and dendrimers have been synthesized. The use of dendritic monomers as building blocks, along with linear monomers, substantially expanded the possibilities of macromolecular design and led to macromolecules of unusual architecture [1]. Incorporation of bulky dendrons into the polymer structure is of both basic and applied interest. The high degree of functional substitution of such polymers opens virtually unlimited opportunities for further transformations, which can lead to novel materials. Modification of the surface of macromolecules, with the aim to impart to them pronounced lyophilic or lyophobic properties, is also possible.

Dendron-containing polymers of several types have been synthesized: monodendrons with a polymer chain in the focal point [2]; dumbbell-like hybrids containing a polymer chain between two monodendrons [3, 4]; and dendron-containing polymers prepared by polymerization of dendron-containing monomers [5, 6].

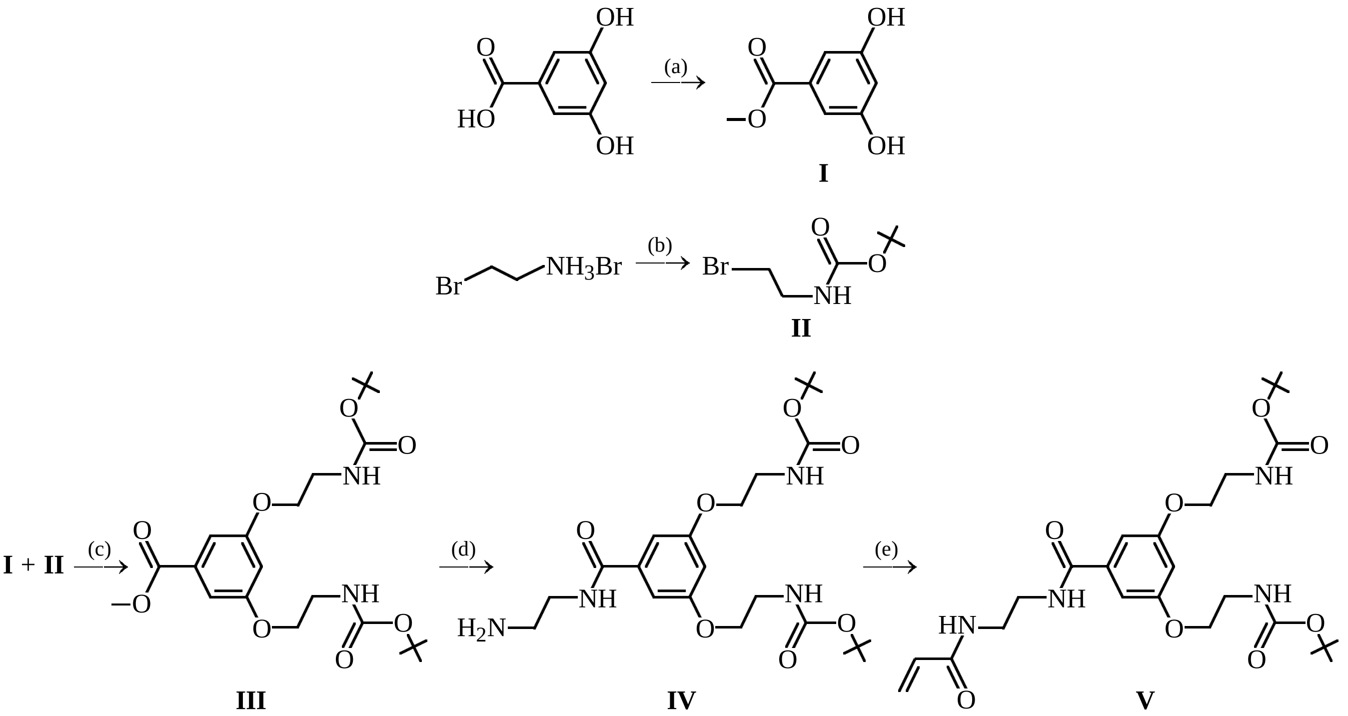
The interest in dendron-containing polymers is due to the possibility of obtaining new speciality materials and using them in biology, medicine, and medical diagnostics [7, 8]. In particular, dendrimers are used for detecting oligonucleotides in DNA diagnostics [9, 10], and polynucleotide dendrimers with fluorescent markers, in microchip DNA diagnostics [11]. Dendritic polyvalent ions can be used to bind proteins [12].

However, only very few studies have been concerned with the possibility of using dendrimers and dendron-containing monomers for preparing modified sorbents [13, 14]. In particular, aliphatic highly branched poly alcohols were used for preparing polymeric chiral stationary phases by postmodification of a macroporous copolymer [13].

The use of vinyl monomers linked through spacers to dendrons containing various terminal groups may be a promising route to adsorption-active macroporous polymers.

Monolithic sorbents, a new generation of stationary phases, are prepared by copolymerization of monomers containing active groups whose high reactivity provides for easy functionalization of the internal surface of the sorbent [15, 16]. Macroporous flow-through layers based on a monolithic copolymer of glycidyl methacrylate (GMA) and ethylene glycol dimethacrylate (EDMA) were developed in the late 1980s–early 1990s [17–21]. Dendron-containing monomers seem promising for preparing functionalized macroporous polymers, since addition of even a small amount of a dendron-containing monomer allows the content of functional groups in the sorbent to be sharply increased. By varying the level of generation and the chemical nature of substituents on the external surface of a dendron molecule, and also by varying the length of a spacer linking the dendron to the acryloyl group, it is possible to control the characteristics of the resulting sorbents.

In the first step, we prepared an acrylic derivative of a dendron containing Boc-protected amino groups by controllable multistep synthesis:



Steps: (a) MeOH, H^+; (b) Boc_2O; (c) $KHCO_3$, DMF; (d) $NH_2(CH_2)_2NH_2$; and (e) CH_2=CHCOCl, NEt_3.

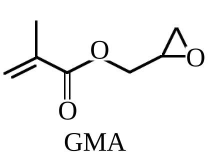
Methyl 3,5-di(2-*tert*-butoxycarbonylaminoethoxy)benzoate **III** was prepared by alkylation of methyl 3,5-dihydroxybenzoate **I** with 2-(*tert*-butoxycarbonylamino)ethyl bromide **II**. It is known that compound **III** can be prepared in the presence of various catalysts [15, 16, 22, 23]. We performed alkylation in the presence of potassium carbonate, with DMF as solvent [15]. The reaction occurs at 40°C within 16 h; yield about 80%.

The starting compounds, methyl 3,5-dihydroxybenzoate **I** and 2-(*tert*-butoxycarbonylamino)ethyl bromide **II**, were prepared as follows: **I**, by esterification of 3,5-dihydroxybenzoic acid with methanol in acid solution [15]; **II**, by protection of the amino group of 2-bromoethylamine hydrobromide with di-*tert*-butyl pyrocarbonate [16].

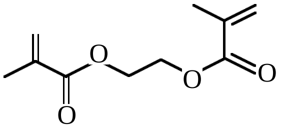
We prepared previously unknown dendron of the first generation **IV** with the amino group at the focal point and terminal Boc-amino groups. To do this, methyl 3,5-di(2-*tert*-butoxycarbonylaminoethoxy)benzoate was treated with excess ethylenediamine at room temperature. The subsequent acylation of the NH_2 group in **IV** with acryloyl chloride in anhydrous methylene chloride in the presence of triethylamine at low temperature yielded dendritic monomer **V**. The structures of the compounds prepared were confirmed by ^1H NMR spectroscopy.

The porosity of monolithic sorbents depends on the monomer ratio, blowing agents used, and polymerization conditions [18]. Therefore, the participation of a dendron-containing monomer in copolymerization can affect the pore structure of the resulting material and, in particular, cause its ordering.

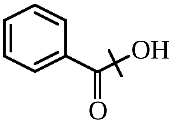
Monolithic macroporous polymers were prepared by radical photoinitiated copolymerization of EDMA, GMA, and acrylic comonomer **V** containing a dendron of the first generation. The reaction was performed in cyclohexanol (a solvent acting as blowing agent [19]) using 2,2-dimethyl-2-hydroxyacetophenone (Darocure 1173) as initiator of radical polymerization [24, 25]:



GMA



EDMA

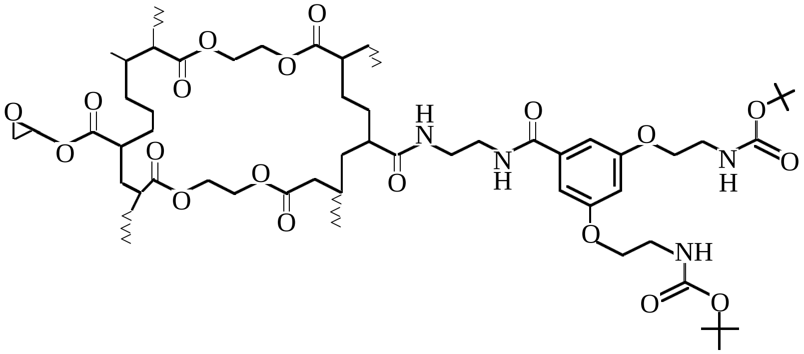


Darocure 1173

We prepared the copolymers containing 10 and 20 mol % **V**.

The IR spectrum confirmed the involvement of the acrylic dendron-containing monomer in the copolymerization. The IR spectrum of the hybrid material contains absorption bands of the N–H (3340 cm^{-1}) and CO (1690 cm^{-1}, amide I; 1520 cm^{-1}, amide II) bonds.

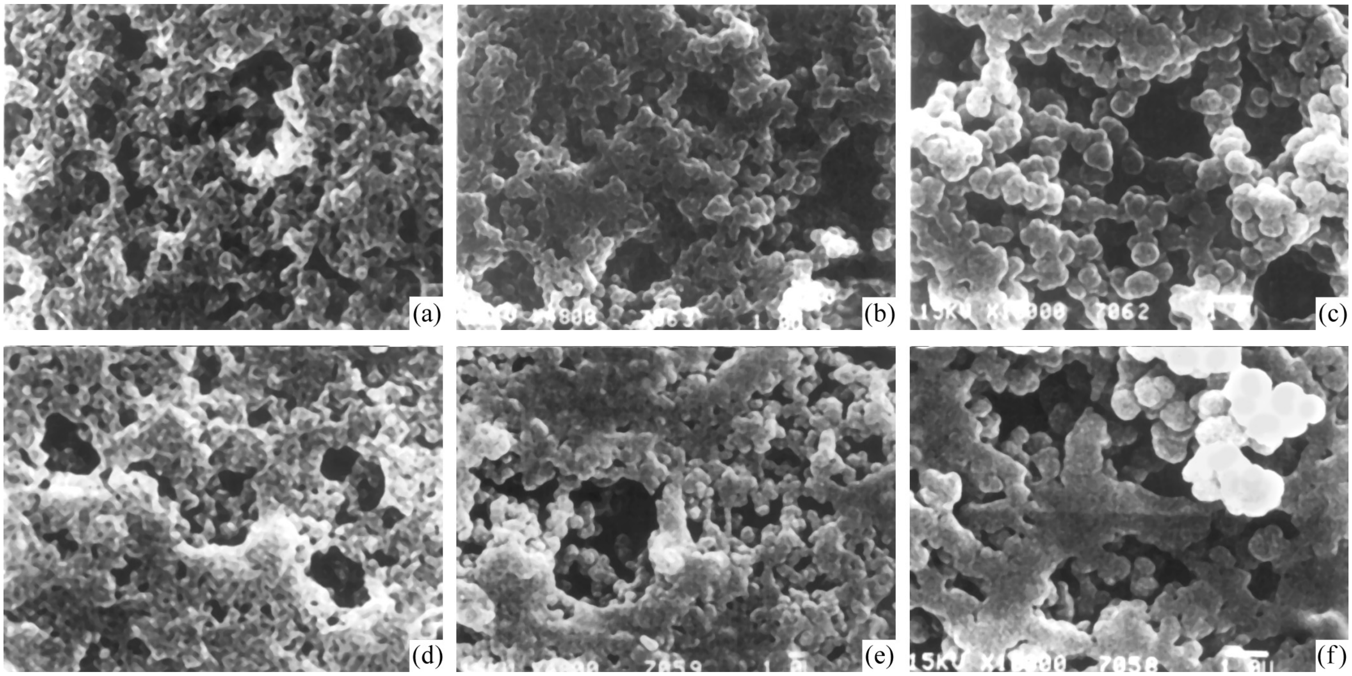
A fragment of the assumed chemical structure of the resulting macroporous polymer is shown below:



The pore structure of the materials obtained was examined by electron microscopy. The polymer layers have a homogeneous internal morphology of the pores. Figure shows plane and cross-sectional electron micrographs of the samples. The polymer containing 10 wt % dendritic monomer has a looser structure. The time required for formation of such monolythic macroporous materials is longer than that for synthesis of GMA–EDMA polymers.

EXPERIMENTAL

GMA was purchased from Fluka (Switzerland); 2,2-dimethyl-2-hydroxyacetophenone, from Merck–Schuchard (Germany); EDMA, cyclohexanol, 3,5-dihydroxybenzoic acid, (2-bromoethyl)amine hydrobromide, and di-*tert*-butyl pyrocarbonate, from Sigma–Aldrich (Germany); and acryloyl chloride, from Reakhim (Russia).



Electron micrographs of microporous monolithic layers prepared by ternary copolymerization of GMA, EDMA, and acrylic monomer. Acrylic monomer content, wt %: (a–c) 10 and (d–f) 20. (a, d) Planar and (b, c, e, f) cross-sectional. Magnification: (a, b, d, e) ×4800 and (c, f) ×10 000.

The ^{1}H NMR spectra were recorded on a Bruker AC300 spectrometer (300 MHz), with deuterated acetone as solvent.

The structural homogeneity of the monoliths was examined by scanning electron microscopy using a JSM-35CF device with cathodic sputtering of a 50–100-Å gold layer.

The IR spectra were measured with a Bruker IFS 88 spectrophotometer (KBr pellets). UV irradiation was performed with a 125-W mercury lamp having a broad radiation spectrum and constant intensity.

Methyl 3,5-di(2-*tert*-butoxycarbonylaminoethoxy)benzoate III. A mixture of 2.82 g (0.017 mol) of methyl 3,5-dihydroxybenzoate, 10.0 g (0.045 mol) of 2-(*tert*-butoxycarbonylamino)ethyl bromide, 10.58 g (0.0765 mol) of potassium carbonate, and 25 ml of DMF was stirred at 80°C for 4 h and left overnight. The precipitate was filtered off, and the solution was concentrated. The product was purified by preparative adsorption column chromatography. Yield 5.08 g (81.5%); colorless crystalline substance. ^{1}H NMR spectrum (acetone-d_6), δ, ppm: 1.47 s [18H, $2C(C\underline{H}_3)_3$], 3.47 m (4H, $2CH_2NH$), 3.86 s (3H, $CO_2C\underline{H}_3$), 4.10 m (4H, $2OC\underline{H}_2$), 6.25 br.s (1H, $N\underline{H}Boc$), 6.76 t (1H, Ar–H), 7.13 d (2H, Ar–H).

Found, %: C 57.98, H 7.81, N 6.21.

$C_{22}H_{34}N_2O_8$.

Calculated, %: C 58.14, H 7.54, N 6.16.

Dendron IV. A solution of 1.5 g (3.28 mmol) of methyl 3,5-di(2-*tert*-butoxycarbonylaminoethoxy)benzoate **III** in 15 ml of methanol was slowly added dropwise to 20 ml of ethylenediamine. The mixture was kept in the dark at room temperature for 3 days, after which the solvent and excess ethylenediamine were distilled off in a vacuum. The residue was dissolved in chloroform, washed with water, dried with sodium sulfate, and concentrated. Yield 1.06 g (67%); oily substance. ^{1}H NMR spectrum (acetone-d_6), δ, ppm: 1.45 s [18H, $2C(C\underline{H}_3)_3$], 3.42 (6H, $2CH_2NH$), 3.60 m (2H, $2CH_2NH_2$), 4.04 t (4H, $2OC\underline{H}_2$), 6.64 t (1H, Ar–H), 7.05 d (2H, Ar–H).

Found, %: C 57.51, H 8.03, N 11.47.

$C_{23}H_{38}N_4O_7$.

Calculated, %: C 57.24, H 7.94, N 11.61.

Acrylic monomer V. To a solution of 0.31 g (0.64 mmol) of dendron **IV** in 5 ml of anhydrous methylene chloride, we added 0.073 g (0.72 mmol) of triethylamine and then, slowly with cooling to 0°C, 0.06 ml (0.66 mmol) of acryloyl chloride. The mixture was stirred for 30 min at 0°C and then for 3 h at room temperature. The reaction course was monitored by TLC. After the reaction was complete, 5 ml of methylene chloride was added, and the mixture was washed with water, dried over sodium sulfate, and concentrated; 0.151 g (44%) of **V** was obtained. ^{1}H NMR spectrum (acetone-d_6), δ, ppm: 1.45 s [18H, $2C(CH_3)_3$], 3.46 t (4H, $2CH_2NH$), 3.60 m (2H, $2CH_2NH_2$), 3.82 s (4H, $NHCH_2CH_2NH$), 4.07 t (4H, $2OC\underline{H}_2$), 5.52 d.d (1H, $CH_2{=}CH$), 5.88 d.d (1H, $CH_2{=}CH$), 6.3 d.d (1H, $CH_2{=}CH$), 6.62 t (1H, Ar–H), 7.05 d (2H, Ar–H).

Found, %: C 58.23, H 7.68, N 10.27.

$C_{26}H_{40}N_4O_8$.

Calculated, %: C 58.19, H 7.51, N 10.44.

The radical polymerization of GMA, EDMA, and acrylic monomer (molar ratios 5.4 : 4 : 0.6 and 4.8 : 4 : 1.2) in cyclohexane in the presence of 0.5% Darocure 1173 was performed under the photoinitiation conditions for 1 h. After the reaction was complete, the polymers obtained were washed with ethanol and dried at 100°C.

CONCLUSIONS

(1) A procedure was developed for preparing dendron of the first generation with the amino group at the focal point and terminal Boc-amino groups and an acrylic monomer derived from it.

(2) A monolithic material can be prepared by photoinitiated ternary copolymerization of glycidyl methacrylate, ethylene glycol dimethacrylate, and an acrylic dendron-containing monomer in the presence of Darocure in a cyclohexanol solution.

(3) Scanning electron microscopy shows that the layers obtained have a homogeneous internal morphologhy of pores.

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