Synthesis of polybetaines with narrow molecular mass distribution and controlled architecture

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Polybetaines with narrow molecular mass distribution (M_w/M_n < 1.25) are synthesised directly for the first time; group-transfer polymerisation of 2-(dimethylamino)ethyl methacrylate (DMAEMA) yields near-monodisperse precursor polymers which are quantitatively betainised under unusually mild conditions using 1,3-propanesultone; block copolymerisation of DMAEMA with alkyl methacrylate comonomers, followed by betainisation, leads to hydrophilic–hydrophobic sulfopropylbetaine block copolymers.

Polybetaines contain both a positive and a negative charge on every monomer residue and were first reported several decades ago.[1] Aqueous solutions of these materials exhibit unusual properties such as the so-called 'anti-polyelectrolye' effect: addition of electrolyte causes expansion, rather than collapse, of the polybetaine chains, Usually polybetaines are synthesised by polymerising zwitterionic monomers based on vinyl pyridines, *N*-vinylimidazole or dialkylaminoalkyl (meth)acrylates *via* free-radical (co)polymerisation, which inevitably results in rather broad molecular mass distributions (M_w/M_n > 2.0).[2–6] Huglin and Radwan reported a comprehensive study[7] of near-monodisperse high molecular mass sulfopropylbetaine homopolymers, but these samples were obtained by careful fractional precipitation, a tedious and time-consuming procedure. Apparently, 'living' polymerisation techniques have not been examined for the synthesis of near-monodisperse polybetaines, presumably since such zwitterionic monomers have very limited solubility in organic solvents such as THF or toluene. An alternative route to polybetaines involves the synthesis of precursor aminopolymers, followed by betainisation using, for example, 1,3-propanesultone.[6,8] However, according to the literature such derivatisation reactions usually require rather extreme conditions (*e.g.* prolonged heating at 120 °C in propylene carbonate or tetramethylene sulfone) and often do not go to completion.[6,8] Moreover, these precursor polymers are generally synthesised *via* free-radical polymerisation and therefore also have broad molecular mass distributions.

As far as we are aware, there have been no reports of the direct synthesis of betaine (co)polymers with either narrow molecular mass distributions or controlled architecture. Here, a facile route to near-monodisperse sulfopropylbetaine homopolymers and block copolymers is described (see Fig. 1). This route takes advantage of the relative ease of betainisation of 2-(dimethylamino)ethyl methacrylate (DMAEMA) polymers.[6] More importantly, since the DMAEMA monomer contains no labile protons, it can be readily (co)polymerised using group-transfer polymerisation (GTP) techniques to produce homopolymers with narrow molecular mass distributions and block copolymers with well defined architectures.[9–12]

DMAEMA homopolymers were synthesised by GTP according to published procedures[9–12] [1-methoxy-1-(trimethylsiloxy)-2-methylpropene initiator and tetrabutylammonium bibenzoate catalyst in THF at room temperature]. Polymer molecular masses were controlled by varying the monomer : initiator molar ratio. Block copolymers were synthesised by addition of the appropriate alkyl methacrylate comonomer to a solution of the 'living' DMAEMA homopolymer. The (co)polymers were purified by removing the THF under reduced pressure and freeze-drying from water overnight. Betainisation was achieved simply by adding 1,3-propanesultone (in 10 mol% excess based on DMAEMA residues) to the (co)polymer in THF at room temperature. Gelation usually occurred within 6 h but the reaction solution was generally left overnight prior to work-up. Unreacted 1,3-propanesultone was removed by Soxhlet extraction using THF.

The four DMAEMA homopolymer precursors were characterised by GPC (THF eluent, two PLgel columns, PMMA standards) and were found to be near-monodisperse, as expected (see Table 1). Their GPC molecular masses were in reasonable agreement with those expected from the corresponding monomer : initiator ratios. After betainisation, the sulfopropylbetaine homopolymers were insoluble in THF and a wide range of common organic solvents ($CHCl_3$, Me_2SO, DMF, methanol, benzene *etc.*). On the other hand, they were soluble in water (and also fluorinated solvents[7] such as 2,2,2-trifluoroethanol and 1,1,1,3,3,3-hexafluoropropan-2-ol). Thus, molecular mass data were obtained using aqueous GPC (Pharmacia Biotech 'Superdex' 200 HR 10/30 column, eluent: 1.0 mol dm^{-3} NaCl containing 50 mmol dm^{-3} Tris buffer at pH 9, PEG/PEO standards). The results are summarised in Table 1.

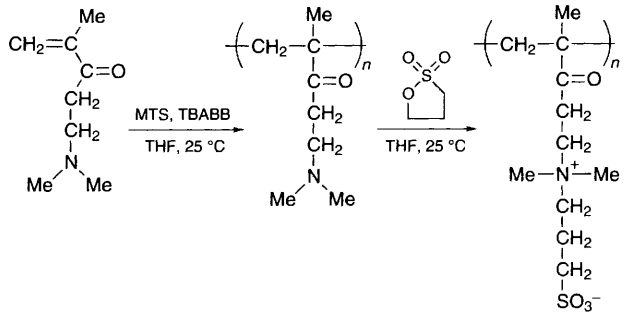

Fig. 1 Reaction scheme for the synthesis of sulfopropylbetaine homopolymers of narrow molecular mass distribution

Table 1 Molecular mass data for the poly[2-(dimethylamino)ethyl methacrylate] precursors and both molecular mass data and degree of betainisation for the sulfopropylbetaine homopolymers

	PDMAEMA homopolymer precursor[a]		Poly-(sulfopropyl-betaine)[b]		Extent of betainisation (%)	
Sample	M_n	M_w/M_n	M_n	M_w/M_n	by ^1H NMR	Microanalysis
HOMO1	5100	1.15	3700	1.13	100±2	90±6
HOMO2	10000	1.15	5300	1.11	100±2	95±6
HOMO3	32000	1.17	28400	1.05	100±2	93±6
HOMO4	71000	1.21	45000	1.16	100±2	92±6

[a] By GPC (THF), calibrated with PMMA standards. [b] By GPC (aqueous 1 mol dm^{-3} NaCl with TRIZMA buffer at pH 9), calibrated with PEO standards.

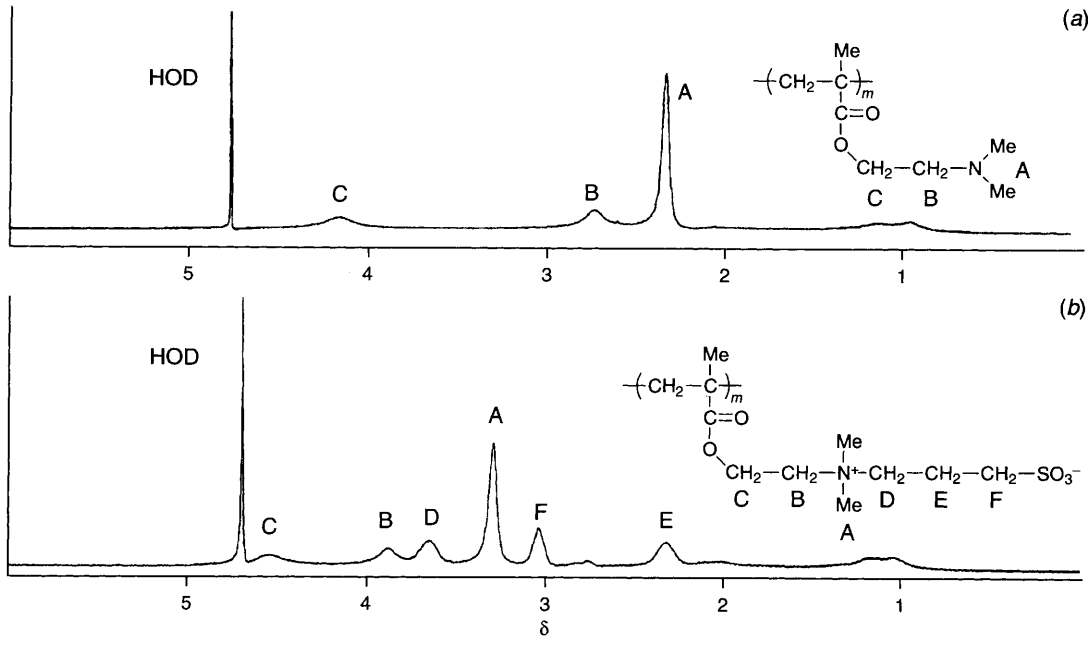

Fig. 2 Proton NMR spectra of (*a*) the poly[2-(dimethylamino)ethyl methacrylate] homopolymer precursor (sample 3 in Table 1) and (*b*) the betainised poly[2-(dimethylamino)ethyl methacrylate] obtained after treatment with 1,3-propanesultone

The narrow molecular mass distributions of the DMAEMA homopolymer precursors are retained in the polysulfopropylbetaines. This is not surprising, since no chain scission would be expected under the remarkably mild conditions used for betainisation. The anomalously low molecular masses obtained for the polysulfopropylbetaines are almost certainly due to their hydrodynamic volumes being significantly different to the non-ionic PEG/PEO calibration standards. NMR spectroscopy confirms that derivatisation is quantitative: betainisation shifts the signal at δ 2.2 due to the six dimethylamino protons in the homopolymer precursor up to δ 3.3, with no evidence for the original signal (see Fig. 2). Sulfur : nitrogen ratios from elemental microanalyses also indicate very high levels of betainisation (see Table 1). Various DMAEMA–alkyl methacrylate block copolymers (DMAEMA content 20–80 mol%, alkyl group may be methyl, *n*-octyl or lauryl) can also be quantitatively betainised under mild conditions. Thus a wide range of sulfopropylbetaine-based block copolymers of well defined architecture are accessible.

The less reactive 1,4-butanesultone can be used instead of 1,3-propanesultone, but lower degrees of betainisation (*ca.* 50–70%) are achieved under the same conditions. On the other hand, since 1,4-butanesultone is much less carcinogenic, betainisation with this reagent may be worthy of further attention.

The literature data regarding the water solubility of betaine homopolymers is rather confusing. Some classes of polybetaines are reported to be soluble in water, whereas others apparently require the addition of electrolyte to induce solubility.[5–7] The sulfopropylbetaine homopolymers synthesised in the present work are readily soluble in water in the presence or absence of salt. On the other hand, incorporation of hydrophobic comonomers (methyl, *n*-octyl or lauryl methacrylate) leads to the micellisation of the betaine block copolymers in water. Photon correlation spectroscopy studies suggest micelle diameters of approximately 20–50 nm for these betaine block copolymers. Surface tension measurements confirm that betainisation significantly reduces the surface activities of the (co)polymers compared to those of the corresponding homopolymer or block copolymer precursors.

In summary, betainisation of GTP-synthesised 2-(dimethylamino)ethyl methacrylate (co)polymers using 1,3-propanesultone proceeds quantitatively under unexpectedly mild conditions. This is a facile route to sulfopropylbetaine homopolymers of narrow molecular mass distribution and the first known examples of betaine block copolymers with well defined architectures. These (co)polymers are currently being evaluated as novel steric stabilisers, surfactants and dispersants.

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References

1 H. Ladenheim and H. Morawetz, *J. Polym. Sci.*, 1957, **26**, 251.
2 R. Hart and D. Timmerman, *J. Polym. Sci.*, 1958, **28**, 638.
3 J. C. Salamone, W. Volksen, S. C. Israel, A. P. Olsen and D. C. Raia, *Polymer*, 1977, **18**, 1058.
4 A. Laschewsky and I. Zerbe, *Polymer*, 1991, **32**, 2070.
5 D. N. Schulz, D. G. Peiffer, P. K. Agarwal, J. Larabee, J. J. Kaladas, L. Soni, B. Handwerker and R. T. Garner, *Polymer*, 1986, **27**, 1734.
6 V. M. Monroy-Soto and J. C. Galin, *Polymer*, 1984, **25**, 121; V. M. Monroy-Soto and J. C. Galin, *Polymer*, 1984, **25**, 254.
7 M. B. Huglin and M. A. Radwan, *Makromol. Chem.*, 1991, **192**, 2433.
8 E. A. Boucher, *Prog. Polym. Sci.*, 1978, **6**, 63.
9 O. W. Webster, W. R. Hertler, D. Y. Sogah, W. B. Farnham and T. V. RanjanBabu, *J. Am. Chem. Soc.*, 1983, **105**, 5706.
10 J. Myktiuk, S. P. Armes and N. C. Billingham, *Polym. Bull.*, 1992, **29**, 139.
11 P. M. Beadle, L. Rowan, J. Mykytiuk, N. C. Billingham and S. P. Armes, *Polymer*, 1993, **34**, 1561.
12 F. L. Baines, S. P. Armes and N. C. Billingham, *Macromolecules*, 1996, **29**, 3416.

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