Electronic Supplementary Material (ESI) for Polymer Chemistry.

Comparing photoswitching of acrylate or methacrylate polymers conjugated with donor-acceptor Stenhouse adducts

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Supporting Information

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1. Materials and Synthesis Methods

1.1. Materials

The reagents were used as received unless otherwise specified. Acetic anhydride (Sigma Aldrich, >98%), acryloyl chloride (Merck, 97%), azobisisobutyronitrile (Sigma Aldrich, 98%), 3-(benzylsulfanylthiocarbonylsulfanyl)propionic acid (BSPA) RAFT agent (synthesized[1]), CPPT RAFT agent (synthesized[2]), dichloromethane (Merck, 99.9%), diethyl ether (Merck, 99.9%), 2,2-dimethyl-1,3-dioxane-4,6-dione (Meldrum's acid, Bio-scientific Pty. Ltd., 99%), dioxane (Merck, 99.9%), di-*tert*-butyl dicarbonate (BOC anhydride, Merck, >98%), ethyl acetate (Merck, 99.9%), furaldehyde (Merck, 99%), hydroxyethyl acrylate (HEA, Sigma Aldrich, 99%), magnesium sulfate ($MgSO_4$, UNIVAR, 99%), methacryloyl chloride (Merck, 97%), 2-(methylamino)ethanol (2-MAE, Sigma Aldrich, >98%), methanol (Merck, 99.9%), *N*-methylpyrrolidone (NMP, Sigma aldrich, 99%), sodium hydrogen carbonate ($NaHCO_3$, UNIVAR, 99%), sodium hydrogen sulfate ($NaHSO_3$, UNIVAR, 99%), sodium sulfate (Na_2SO_4, Aldrich, > 99%), triethylamine (TEA, Chem-Supply Pty. Ltd., 99%), trifluoroacetic acid (VWR International, 99%).

1.2. Characterization Methods

Nuclear Magnetic Resonance (NMR)

A Bruker Avance III 300 and 400 MHz, 5 mm BBFO probe (^{1}H, 300.17 MHz) was used for routine spectroscopy. Further characterization and higher temperature experiments were conducted using a Bruker DMX 600 MHz spectrometer (^{1}H, 600.13 MHz) with a QNP probe. Solvents employed were $CDCl_3$, DMSO-d_6, and chemical shifts are expressed in ppm relative to residual solvent peaks. Measurements were performed at 25 °C unless otherwise stated. The raw data were processed using Bruker TOPSPIN 3.6.1 software. Signals in the NMR spectra are reported as broad (br), singlet (s), doublets (d),triplets (t), quartets (q), or unclear multiplets (m).

Size Exclusion Chromatography (SEC)

Experiments were performed on a Shimadzu modular system with SIL-10AD autoinjector, LC-10AT pump, CTO-10A oven, 5.0-µm bead guard column (50 mm × 7.8 mm) followed by four 300 mm × 7.8 mm linear columns (Phenomenex) with 500, 103, 104, 105 Å pore size and 5 µm particle size. The solvent system was *N*,*N*-dimethylformamide (DMF, HPLC grade) with 0.05% w/v of 2,6-dibutyl-4-methylphenol and 0.03% w/v of LiBr. Flow rate was 1 mL min^{-1} at 50 °C and a refractive index detector was used (Shimadzu RID-10A). The calibration was performed using narrow polydispersity PMMA standards (0.5−1000 kDa) purchased from Polymer Laboratories.

Dynamic Light Scattering (DLS)

A Malvern Zetasizer instrument was employed with a He–Ne laser (4 mV) operating at 632 nm. The detection angle was 173° and the sample temperature was kept at 25 °C.

Transmission Electron Microscopy (TEM)

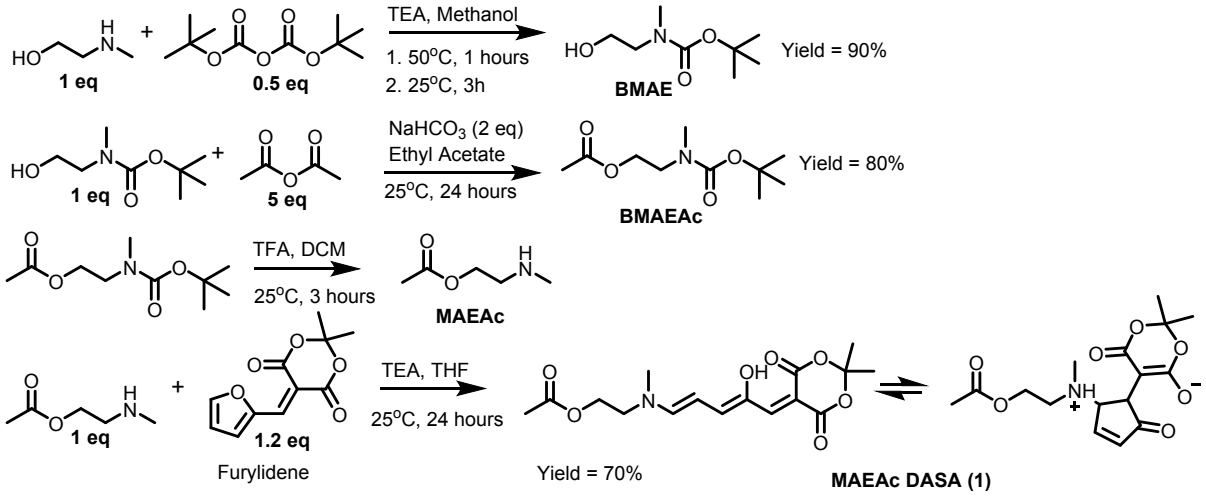
A JEOL1400 TEM operating at 100 kV and equipped with a Gatan CCD camera and a FEI Tecnai G2 20 TEM operating at 200 kV and a BM Eagle digital camera for image acquisition. Samples were deposited on a 200 mesh copper grids coated with Formvar and carbon. 5 μL of sample at a concentration ranging from 0.5 to 0.2 mg mL^{-1} were carefully placed on a suspended grid. After 2 min the liquid was blotted away with filter paper and the grid was air dried for at least 1 h before imaging. If desired, a 2 wt% solution of uranyl acetate in water was used to stain the samples for 5 min, excess solution was then blotted away and the grid was air dried for at least 1 h.

UV−Vis spectroscopy

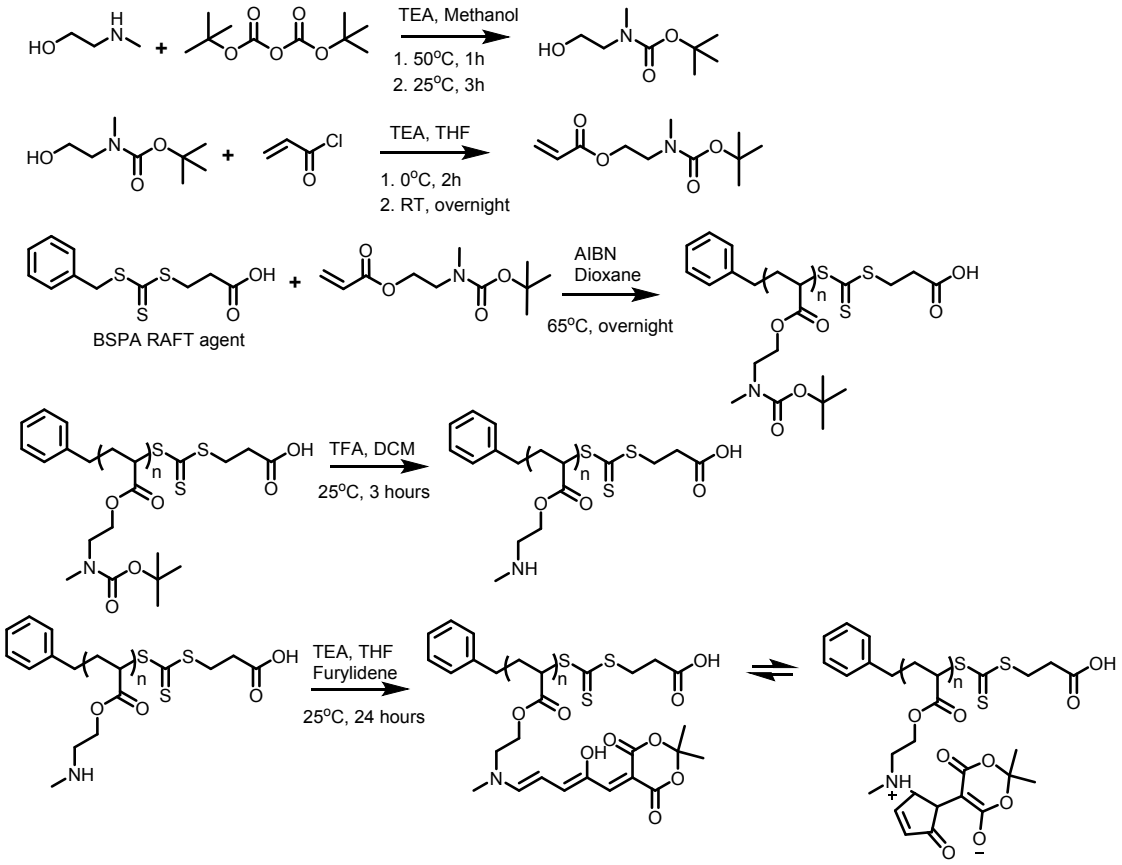
A Cary 60 UV-Visible spectrophotometer equipped with a Cary Single Cell Peltier Accessory or an Agilent Cary 8454 UV-Vis Diode Array System equipped with an Agilent PCB 1500 Water Peltier System. Spectra were acquired in DMSO, water, DCM, DMAc and toluene at a concentration between 0.5 and 1 mg mL^{-1} of polymer. Scan rate was 600 nm min^{-1}.

1.3. Synthesis schemes

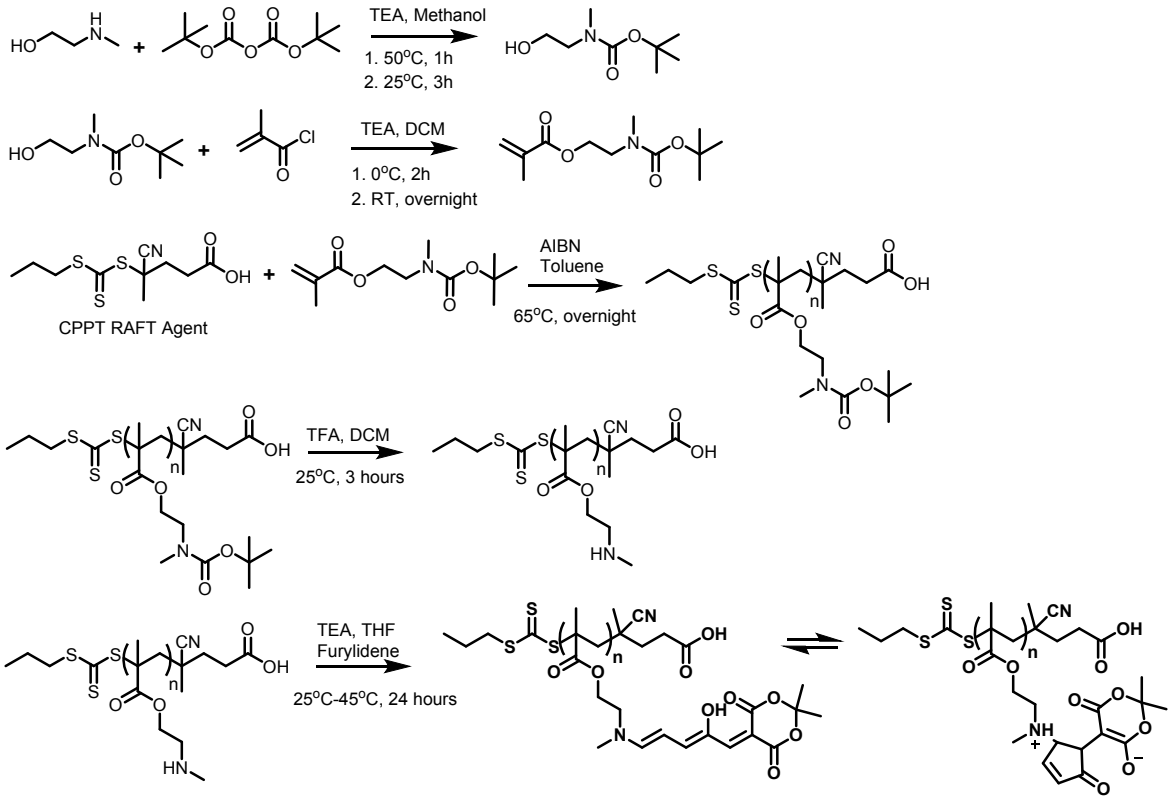
Model DASA (MAEAc, 1)



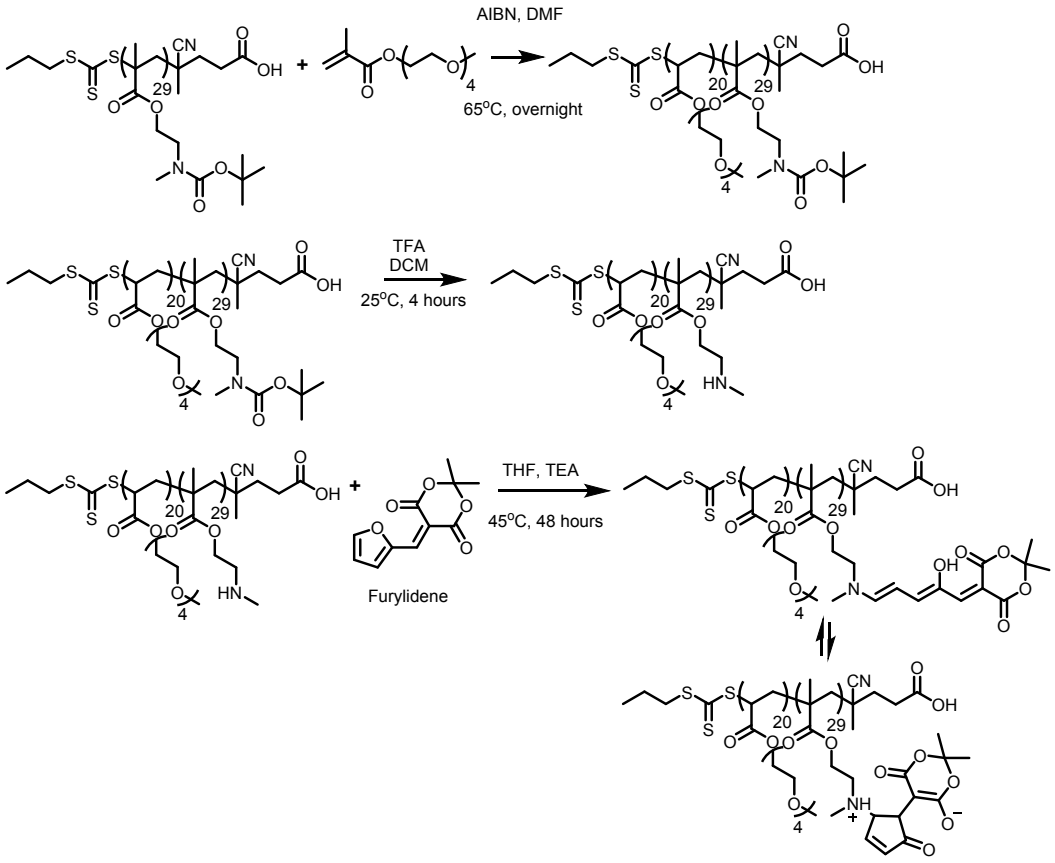
Homopolymer acrylate DASA (pMAEA, 2)



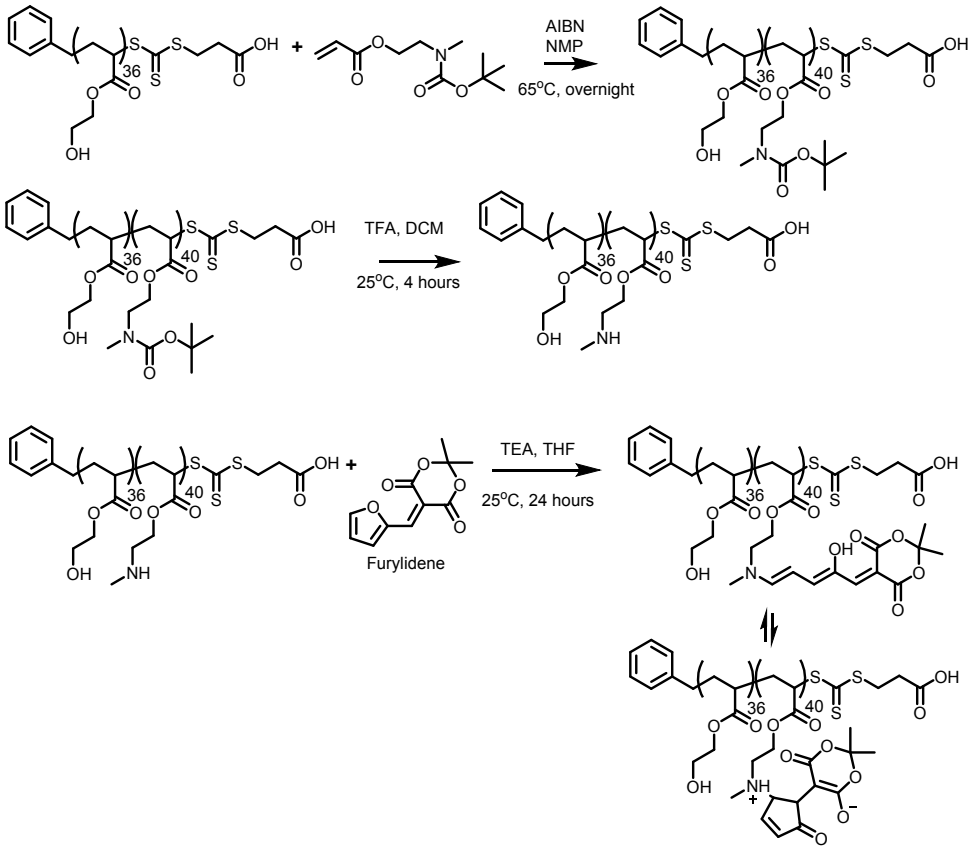
Homopolymer methacrylate DASA (pMAEMA, 3)



Methacrylate block copolymer DASA (pMAEMA$_{29}$-*b*-pPEGMEMA$_{20}$, 4)

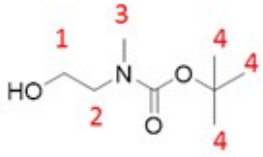


Acrylate block copolymer DASA (pHEA$_{36}$-*b*-pMAEA$_{40}$, 5)



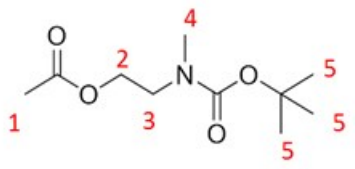
1.4. Synthesis procedures

The synthesis of Boc-protected 2-(methylamino) ethanol (BMAE)



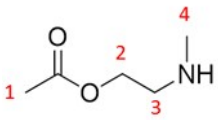
2-Methylamino ethanol (1.0 g, 0.013 mol), di-tert-butyl-dicarbonate (1.45 g, 0.007 mol), and triethylamine (0.36 g, 0.004 mol) were dissolved in methanol (9.96 ml). The reaction mixture was stirred at 50 °C for 1 h and then further reacted at room temperature for 3 h. The solvent was then removed under reduced pressure on a rotary evaporator. Water (50 mL) was added to the pale yellow oil and the product was extracted using diethyl ether (3 × 30 mL). The organic layers were combined, dried over magnesium sulfate, filtrated and the solvent was removed under reduced pressure to yield pale yellow oil. (Yield = 90%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.4 (s, 9H, **4**), δ 2.9 (s, 3H, **3**), δ 3.3 (t, 2H, **2**), δ 3.7 (t, 2H, **1**).

The Synthesis of Boc-2-(methylamino) ethyl acetate (BMAEAc)



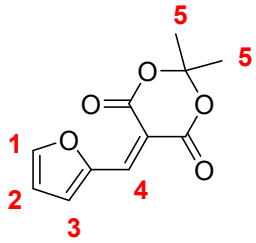
BMAE (0.175 g, 1.0 mmol), acetic anhydride (0.51 g, 5.0 mmol), $NaHCO_3$ (0.168 g, 2.0 mmol) was dissolved in ethyl acetate (6 ml) and stirred at room temperature for 24 hours. The progress of the reaction was followed by Thin Layer Chromatography (TLC). Once the starting material was consumed the mixture was filtrated and the filtrate was concentrated. To the residue, DCM (15 ml) was added and extracted against water (3 × 5 ml). The organic layer was collected and dried under vacuum. The liquid product was further purified by column chromatography with 1:1 hexane/ ethyl acetate (v/v) as the mobile phase giving a pale yellow liquid as a product. (Yield = 80%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.4 (s, 9H,**5**), δ 2.1 (s, 3H, **1**), δ 2.9 (s, 3H,**4**), δ 3.5 (br, 2H, **3**), δ 4.2 (br, 2H, **2**).

Deprotection of Boc-2-(methylamino) ethyl acetate (MAEAc)



BMAEAc (101 mg, 0.46 mmol) was dissolved in DCM (5 ml) and TFA (180 µL, 2.32 mmol) was added dropwise into the solution. The reaction was left to stir at room temperature for 4 hours while monitored by TLC. After completion, methanol was added into the mixture to quench the reaction. The sample was dried in vacuo and then purified by column chromatography using chloroform and 5% methanol mixture as an eluent yielding a pale yellow liquid. (Yield = 28%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.1 (s, 3H, **1**), δ 2.8 (s, 3H, **4**), δ 3.2 (br, 2H, **3**), δ 3.9 (t, 2H, **2**).

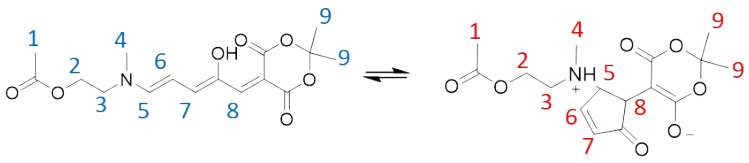
The synthesis of Furylidene



To a stirred solution of Meldrum's acid (1.45 g, 10 mmol) in water (30 ml) was added furaldehyde (970 mg, 10 mmol). The solution was stirred at 75°C for 2 hours yielding a dark yellow precipitate. The precipitate was collected in vacuo and washed with cold water (40 ml). The solid was dissolved in DCM (50 ml) and washed sequentially with saturated $NaHSO_3$ (30 ml), followed by H_2O (30 ml), then saturated Na_2CO_3 (30 ml) and brine (30 ml). The organic layer was then dried over $MgSO_4$, filtered and dried in vacuo to yield furylidene

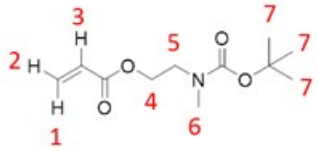
as bright yellow crystalline powder. ^{1}H NMR (400 MHz, CD_3CN) δ 8.32 (d, J = 3.9 Hz, 1H, **3**), 8.19 (s, 1H, **4**), 7.98 (dd, J = 1.7, 0.8 Hz, 1H, **1**), 6.81 (ddd, J = 3.90, 1.7, 0.8 Hz, 1H, **2**), 1.73 (s, 6H, **5**).

The synthesis of model DASA (MAEAc DASA)



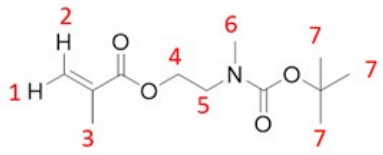
In general, the deprotected MAEAc was dissolved in anhydrous THF with a concentration of 10 mg/ml. TEA (excess) was added to deprotonate the amine. Furylidene (1.2 molar equivalent) was added into the solution where colour change from pale yellow to bright pink was observed. The reaction was left to stir in the dark for 24 hours and the product was collected by filtration, washed with cold THF and dried under vacuum. The product was isolated as a deep red solid (70% yield). ^{1}H NMR (600 MHz, DMSO-d_6) Linear isomer: δ 1.50 (s, 6H, **9**), δ 1.61 (s, 3H, **1**), δ 3.33 (s, 3H, **4**), δ 3.83 (t, 2H, **3**), δ 4.31 (t, 2H, **2**), δ 6.02 (t, 1H, **6**), δ 6.70 (s, 1H, **8**), δ 7.19 (d, 1H, **7**), δ 7.99 (d, 1H, **5**). Cyclic isomer: δ 1.50 (s, 6H, **9**), δ 1.61 (s, 3H, **1**), δ 3.33 (s, 3H, **4**), δ 3.72 (br, 1H, **8**), δ 3.83 (br, 2H, **3**), δ 4.29, (br, 2H, **2**), δ 4.51 (br, 1H, **5**), δ 6.48 (br, 1H, **7**), δ 7.67 (br, 1H, **6**).

The synthesis of Boc-2-(methylamino) acrylate (BMAEA)



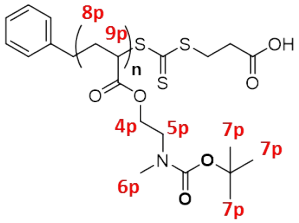
BMAE (6.85 g, 0.04 mol) and triethylamine (3.95 g, 0.04 mol) were dissolved in anhydrous THF (159 ml) and the reaction mixture was cooled to 0°C in an ice bath. Acryloyl chloride (3.43 g, 0.04 mol) was then added dropwise while stirring. The reaction was left to stir in an ice bath for 2 hours and then left to react further at room temperature overnight. Any solids were removed by filtration and the filtrate was concentrated under reduced pressure. The product was purified by gel column chromatography using chloroform and 5% methanol as an eluent. The desired product was isolated as a clear oil (71% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.4 (s, 9H, **7**), δ 2.9 (s, 3H, **6**), δ 3.5 (br, 2H, **5**), δ 4.3 (br, 2H, **4**), δ 5.9 (dd, 1H, **2**), δ 6.2 (dd, 1H, **1**), δ 6.4 (dd, 1H, **3**).

The synthesis of Boc-2-(methylamino) methacrylate (BMAEMA)



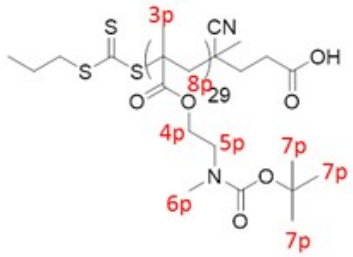
BMAE (0.5 g, 2.9 mmol) were dissolved in anhydrous DCM (9.1 ml) and the reaction mixture was cooled to 0°C in an ice bath. Methacryloyl chloride (0.3 g, 2.9 mmol) was added dropwise while stirring. The reaction was left to stir in an ice bath for 2 hours and then left to react further at room temperature overnight. Any solids were removed by filtration and the filtrate was concentrated under reduced pressure. The filtrate was dissolved in DCM (50 ml) and washed with 1M HCl (50 ml), then brine (50 ml) and finally milliQ water (50 ml). The collected organic phase was dried over Na_2SO_4. The dried product was then further purified by column chromatography in cyclohexane/ ethyl acetate with gradient from 9:1 to 3:1. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.4 (s, 9H, **7**), δ 2.0 (s, 3H, **3**), δ 2.9 (s, 3H, **6**), δ 3.5 (br, 2H, **5**), δ 4.3 (br, 2H, **4**), δ 5.6 (dd, 1H, **1**), δ 6.2 (dd, 1H, **2**).

The synthesis of BMAEA homopolymer (pBMAEA)



The polymerisations were carried out via RAFT polymerization. BSPA RAFT agent was used to polymerize acrylate monomers (see structure in Section 1.3). BSPA RAFT agent (7.5 mg, 29 µmol), BMAEA monomer (661 mg, 3 mmol), AIBN initiator (0.9 mg, 5.8 µmol) were dissolved in dioxane (2 ml). NMR sample (20 µL) before and after polymerization were collected to determine monomer conversion. The mixture underwent five freeze-pump-thaw cycles at pressure <5x10^{-2} mbar until no air bubbles were present. Dry N_2 gas was introduced, and the polymerisation was started at 65°C. The reaction was left to stir overnight. . The polymer was purified by precipitation in n-hexane. ^{1}H NMR (400 MHz, DMSO-d_6) δ 1.4 (s, 9H, **7p**), δ 1.7 (br, 1H, **8p**), δ 2.3 (br, 2H, **9p**), δ 2.9 (br, 3H, **6p**), δ 3.5 (br, 2H, **5p**), δ 4.3 (br, 2H, **4p**).

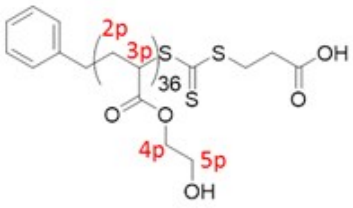
The synthesis of BMAEMA homopolymer (pBMAEMA)



The polymerisations were carried out via RAFT polymerization. CPPT RAFT agent was used to polymerize methacrylate monomers (see structure in Section 1.3). CPPT RAFT agent (15 mg, 0.055 mmol), BMAEMA monomer (667 mg, 2.74 mmol), AIBN initiator (1.8 mg, 0.011 mmol) were dissolved in Toluene (2.74 ml). NMR sample (20 µL) before and after polymerization were collected to determine monomer conversion.. The mixture underwent five freeze-pump-thaw cycles at pressure <5x10^{-2} mbar until no air bubbles were present. Dry

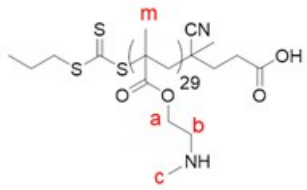
N_2 gas was introduced, and the polymerisation was started at 65°C. The reaction was left to stir overnight. The polymer was purified by precipitation in n-hexane. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.0 (br, 2H, **8p**), δ 1.5 (br, 9H, **7p**), δ 2.0 (br, 3H, **3p**), δ 3.0 (br, 3H, **6p**), δ 3.6 (br, 2H, **4p**), δ 4.2 (br, 2H, **4p**).

The synthesis of HEA homopolymer (pHEA)



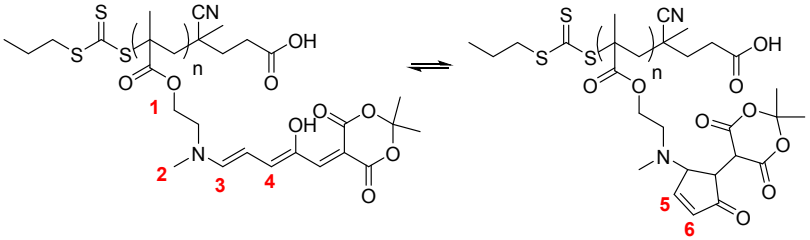
The polymerisations were carried out via RAFT polymerisation method. BSPA RAFT agent (10 mg, 0.38 mmol), HEA monomer (882 mg, 3.8 mmol), AIBN initiator (1.26 mg, 0.076 mmol) were dissolved in dioxane (3.8 ml). NMR sample (20 µL) before and after polymerization were collected to determine monomer conversion.. The mixture underwent freeze-pump-thaw cycles for 5 times at pressure <$5x10^{-2}$ mbar until no air bubbles were present. Dry N_2 gas was introduced, and the polymerisation was started at 65°C. The reaction was left to stir overnight. The polymer was purified by precipitation in n-hexane. ^{1}H NMR (400 MHz, DMSO-d_6) δ 1.6 (br, 2H, **2p**), δ 2.2 (br, 1H, **3p**), δ 3.6 (br, 2H, **5p**), δ 4.0 (br, 2H, **4p**).

Deprotection of homopolymer (pMAEA and pMAEMA)



In general, the homopolymer (50 mg) is dissolved in DCM (5 ml). TFA (10 molar equivalents to BMAEA or BMAEMA units) was added dropwise to the solution. The reaction was left to stir at room temperature for 3 hours and then quenched with a few drops of methanol. The sample was purified by dialysis against water (membrane MWCO 3,500 Da). ^{1}H NMR (400 MHz, D_2O, pH 2-7) δ 1.80 (s, 3H, **m**), δ 2.70 (s, 3H, **c**), δ 3.10 (t, 2H, **b**), δ 3.75 (t, 2H, **a**).

The synthesis of polymer DASA



In general, the deprotected polymer was dissolved in anhydrous THF with a concentration of 10 mg/ml. TEA (1.5 molar equivalent) was added to deprotonate the amine. Furylidene (1 molar equivalent) was added into the solution, resulting in an instant color change pale yellow to bright pink is observed. The reaction was left to stir in the dark for 24 hours, during which the product precipitated. The product was collected by filtration, washed with cold THF, and dried under a stream of nitrogen (50% yield). ^{1}H NMR (600 MHz, DMSO-d_6, pH 2-7) δ 3.0 (br, 3H, **2**), δ 4.2 (br, 2H, **1**), δ 6.2 (br, 1H, **6**), δ 7.5 (br, 1H, **5**).

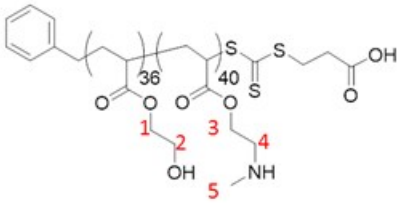
Chain extension of pBMAEMA$_{29}$ macro RAFT with PEGMEMA monomer (pBMAEMA$_{29}$-*b*-pPEGMEMA$_{20}$)

pBMAEMA(29) macro RAFT agent (57 mg, 0.008 mmol), PEGMEMA monomer (57 mg, 0.15 mmol), AIBN (0.25 mg, 0.002 mmol) was dissolved in DMF (0.155 ml). The mixture was purged by bubbling with N_2 gas and then reacted overnight at 65°C. The quantitative conversion was determined by comparing ^{1}H NMR samples collected before and after polymerization.

Chain extension of pHEA macro RAFT with BMAEA monomer (pHEA$_{36}$-*b*-pBMAEA$_{40}$)

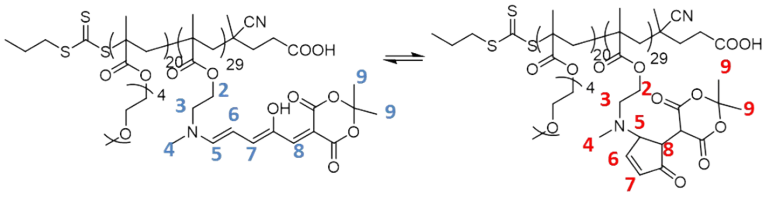
pHEA macro RAFT agent (30 mg, 0.01 mmol), BMAEA monomer (115 mg, 0.5 mmol), AIBN (0.33 mg, 0.002 mmol) was dissolved in NMP (0.5 ml). The mixture was degassed by five freeze-pump-thaw cycles and then reacted for 24 hours at 65°C. The quantitative conversion was determined by comparing ^{1}H NMR samples collected before and after polymerization.

Deprotection of block copolymer



In general, the polymer (50 mg) is dissolved in DCM (5 ml). TFA (10 molar equivalents to BMAEA units) was added dropwise to the solution. The reaction was left to stir at room temperature for 3 hours and then quenched with a few drops of methanol. The sample was purified by dialysis against water for 2 days (changing the water every 4 hours) and then lyophilized. ^{1}H NMR (400 MHz, CD_3OD) δ 2.8 (s, 3H, **5**), δ 3.4 (br, 2H, **4**), δ 3.8 (br, 2H, **1**), δ 4.2 (br, 2H, **2**), δ 4.4 (br, 2H, **3**).

The synthesis of block copolymer DASA



In general, the deprotected block copolymer was dissolved in anhydrous THF with a concentration of 10 mg/ml. TEA (1.5 molar equivalent) was added to deprotonate the amine. Furylidene (1 molar equivalent) was added into the solution where colour change from pale yellow to bright pink is observed. The reaction was left to stir in the dark for 24 hours and then the product was filtered out and washed with cold THF. In the case of methacrylate DASA block copolymer, the product remains soluble in THF. The crude solution was directly used for micellisation process and then purified by dialysis against water with a 3,500 Da dialysis membrane. ^{1}H NMR (600 MHz, DMSO-d_6) Linear Isomer: δ 4.1 (br, 2H, **4**), δ 4.2 (br, 2H, **2**), δ 6.3 (t, 1H, **6**), δ 6.5 (s, 1H, **8**), δ 6.8 (d, 1H, **7**), δ 7.2 (d, 1H, **5**). Cyclic isomer: δ 6.2 (br, 1H, **7**), δ 7.5 (br, 1H, **6**).

Self-assembly of block copolymer DASA

In general, the bock copolymer solution (10 mg/ml) is dissolved in THF. The solution was injected into MilliQ water at a rate of 0.5 ml/hour to reach a micelle concentration of 5 mg/ml. The sample is left to stir for 30 minutes and then purified by dialysis against water with a 3.500 Da dialysis membrane.

DASA conjugation efficiency on polymer and isomer ratio in DMSO-d_6

Table S1. DASA conjugation efficiency and isomer ratio (in DMSO-d_6) calculated from ^{1}H NMR integration for short and long acrylate and methacrylate homopolymer reacted at 25, 45 and 65°C. The ratio of cyclic and linear DASA adducts was determined after incubation in DMSO in the dark overnight.

Polymer	Sample No.	Sample	Temperature (°C)	Conjugation efficiency[a]	Isomer Ratio (in DMSO-*d6*)[b]	
					Cyclic	Linear
Acrylate	2A	pMAEA(23) DASA	25	>99%	75%	25%
			45	>99%	87%	12%
			65	>99%	85%	15%
	2B	pMAEA(101) DASA	25	>99%	93%	7%
			45	>99%	91%	9%
			65	>99%	94%	6%
Methacrylate	3A	pMAEMA(29) DASA	25	77%	94%	6%
			45	>99%	91%	9%
			65	>99%	85%	15%
	3B	pMAEMA(92) DASA	25	>99%	91%	9%
			45	>99%	92%	8%
			65	>99%	88%	12%
	4	pMAEMA(29)-*b*-pPEGMEMA(20) DASA	45	>99%	57%	43%

[a] The conjugation efficiency calculation was described in ESI 2.19, comparing the integration of polymer pendant to the DASA cyclic and linear peaks [b] The ratio between cyclic and linear was also described in ESI 2.19.

2. NMR Characterizations and calculations

2.1. ^{1}H NMR spectra of BMAE

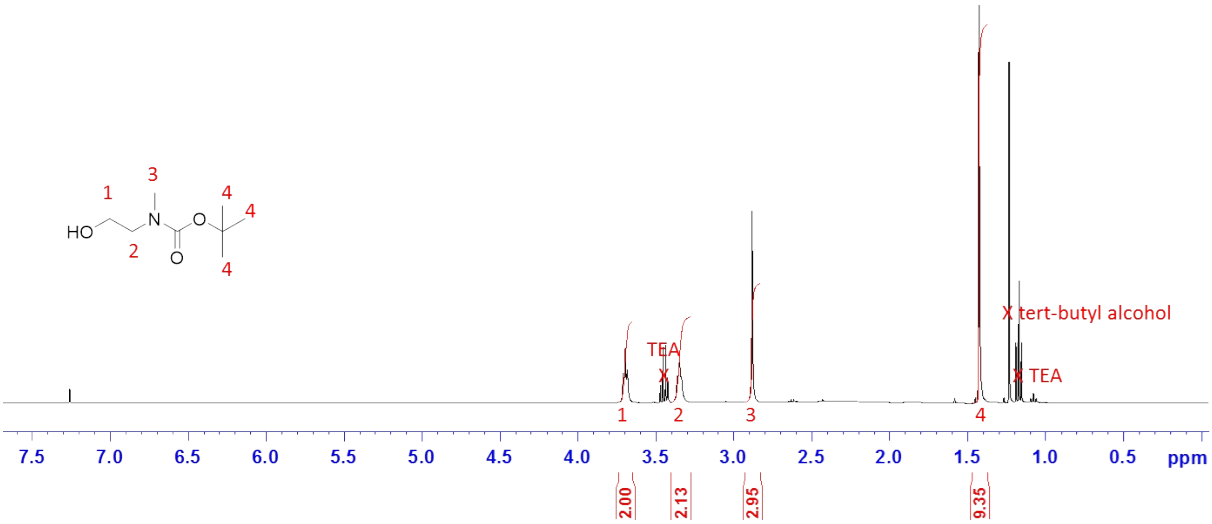


Figure S1. ^{1}H NMR spectra of BMAE (400 MHz, $CDCl_3$)

2.2. ^{1}H NMR spectra of BMAEAc

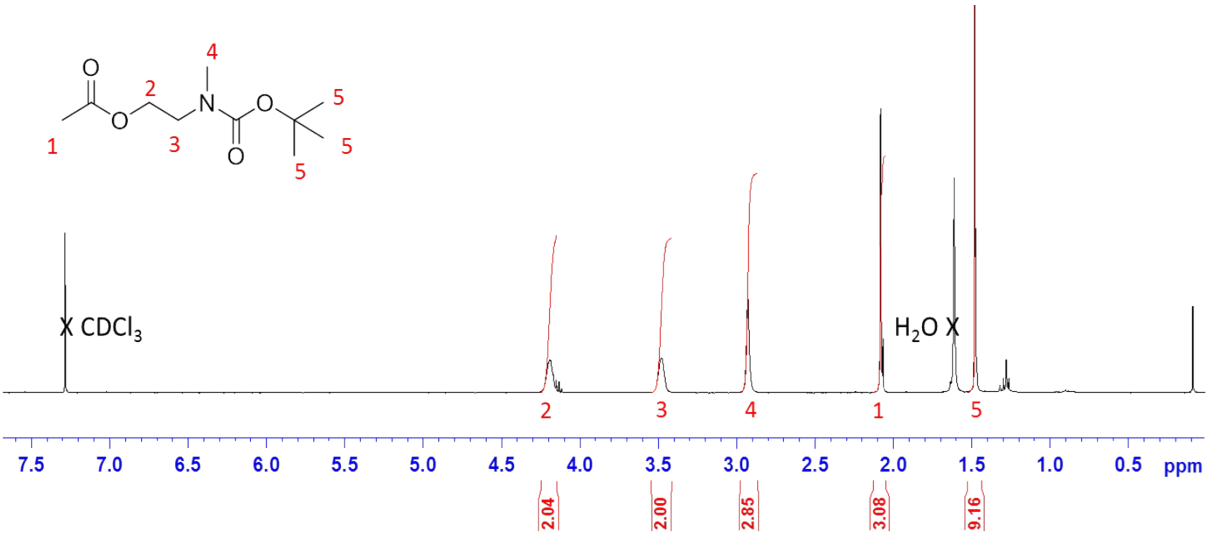


Figure S2. ^{1}H NMR spectra of BMAEAc (400 MHz, $CDCl_3$)

2.3. ^{1}H NMR spectra of BMAEA (acrylate) monomer

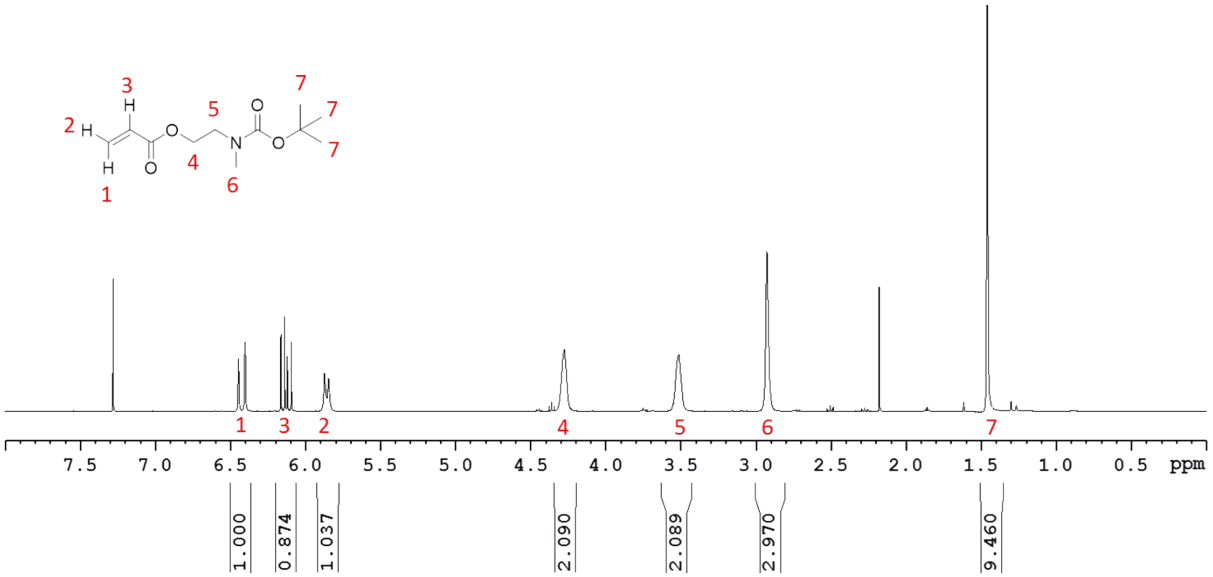


Figure S3. ^{1}H NMR spectra of BMAEA monomer (400 MHz, $CDCl_3$)

2.4. ^{1}H NMR spectra of BMAEMA (methacrylate) monomer

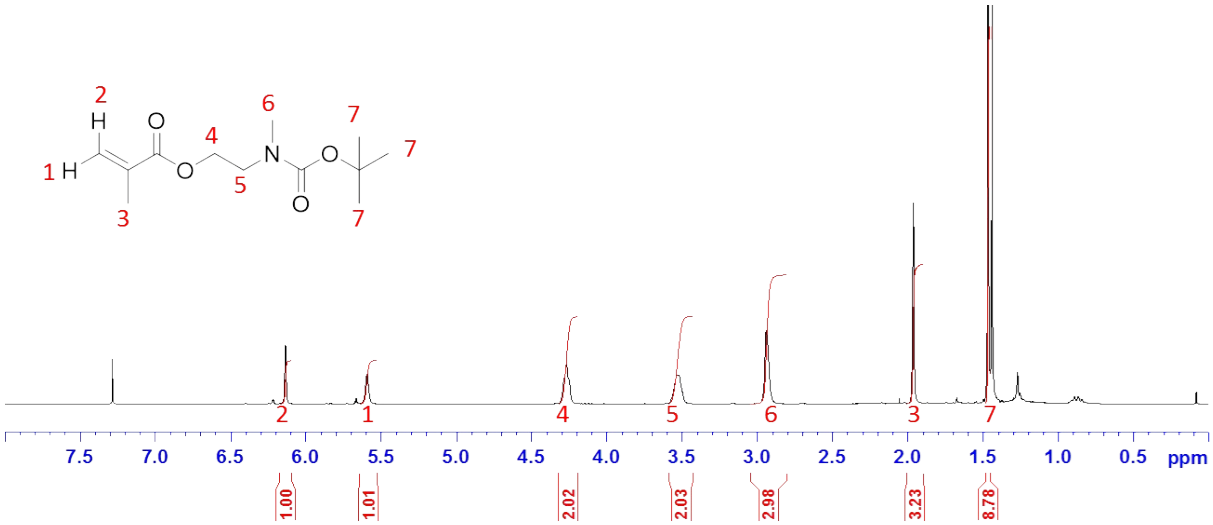


Figure S4. ^{1}H NMR spectra of BMAEMA monomer (400 MHz, $CDCl_3$)

2.5. ^{1}H NMR spectra of pBMAEA$_{23}$ and calculation of monomer conversion

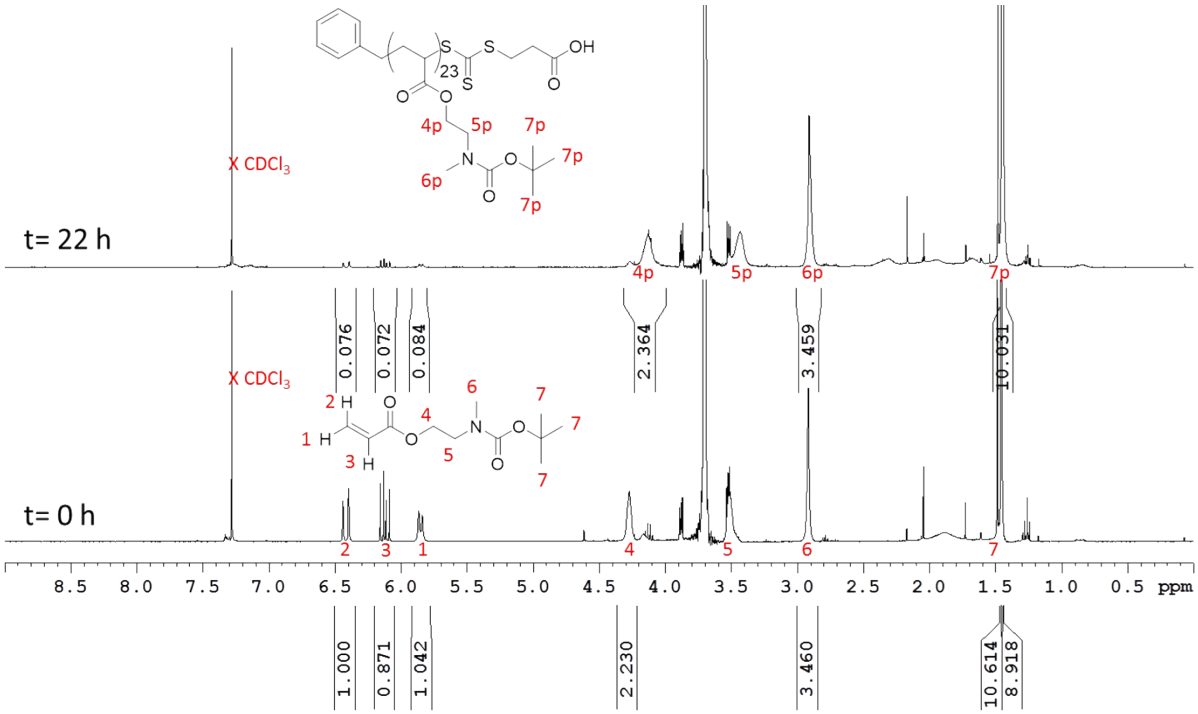


Figure S5. ^{1}H NMR spectra of BMAEA polymerization (DP 25). Bottom figure is crude at t=0 h, and top figure is crude at t= 22 h. Conversion is 93% (400 MHz, $CDCl_3$).

The monomer conversion was calculated by:

Equation 1. Monomer conversion calculation by integration number ratio at t = final and t= 0 with integration of -N-CH_3 (6) at t=final calibrated to match the integration at t=0 as internal standard.

$$Conversion\ (\%) = 1 - \frac{Average\ I\ of\ Monomer\ left\ at\ t = final}{Average\ I\ of\ Monomer\ at\ t = 0} \times 100\%$$

And the number of repeating units is calculated by:

$$Number\ of\ repeat\ units = Conversion\ (\%) \times DP$$

Where I = integration number, DP = degree of polymerization, calculated by the molar ratio of the monomer to the RAFT agent where RAFT molar ratio is 1. The amount of monomer corresponds to the average of the integration number of the monomer at δ 6.4. 6.2 and 5.8 ppm. Thus,

$$1 - \frac{I^{monomer}_{t = 22\ h}}{I^{monomer}_{t = 0h}} \times 100\%$$

$$= 1 - \frac{\frac{0.076 + 0.072 + 0.084}{3}}{\frac{1.000 + 0.872 + 1.042}{3}} \times 100\% = 93\%$$

2.6. ^{1}H NMR spectra of pBMAEA$_{101}$

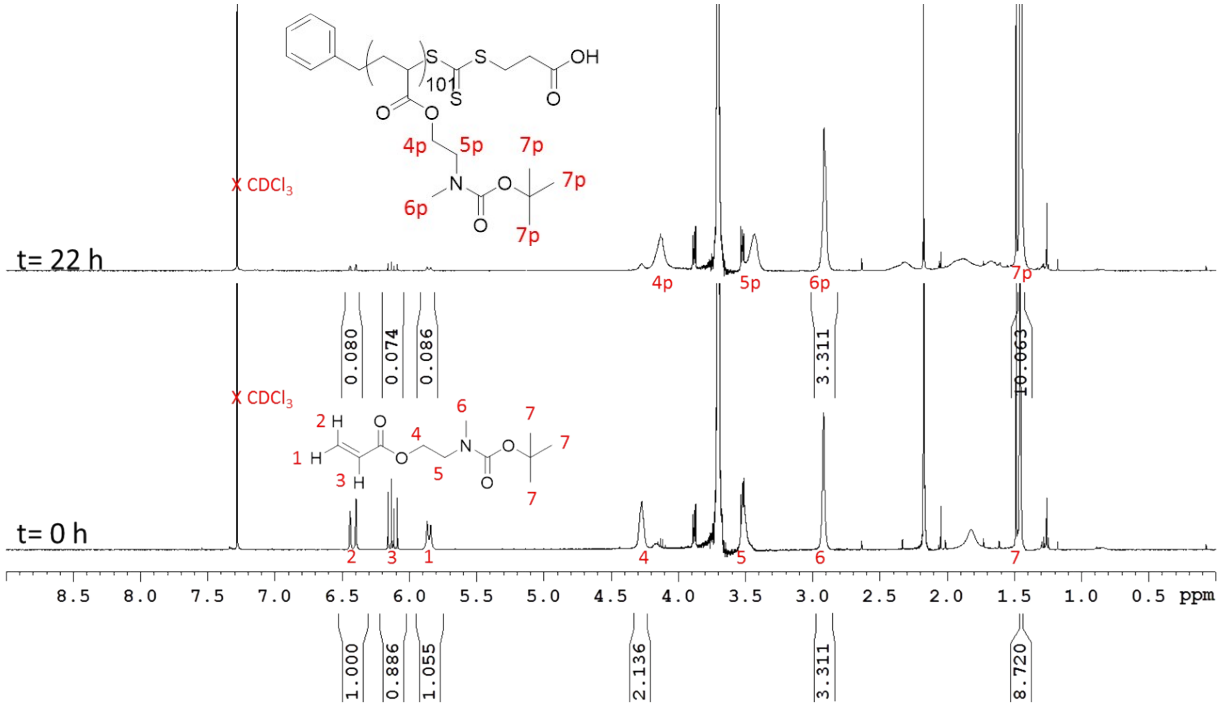


Figure S6. ^{1}H NMR spectra of BMAEA polymerization (DP 110). Bottom figure is crude at t=0 h, and top figure is crude at t= 22 h. Conversion is 92% (400 MHz, $CDCl_3$).

2.7. ^{1}H NMR spectra of pBMAEMA$_{29}$

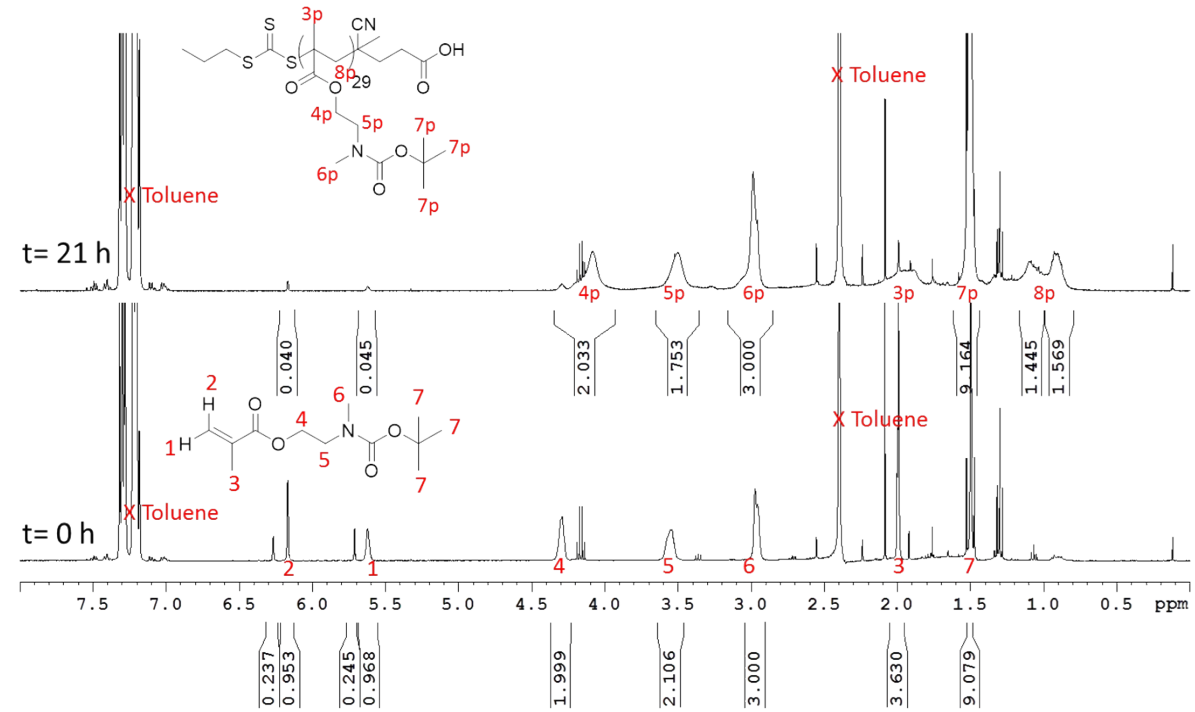


Figure S7. ^{1}H NMR spectra of pBMAEMA$_{29}$ polymerization. Bottom figure is crude at t=0 h, and top figure is crude at t=21 h. Conversion is 96%. (400 MHz, $CDCl_3$).

2.8. ^{1}H NMR spectra of pBMAEMA$_{92}$

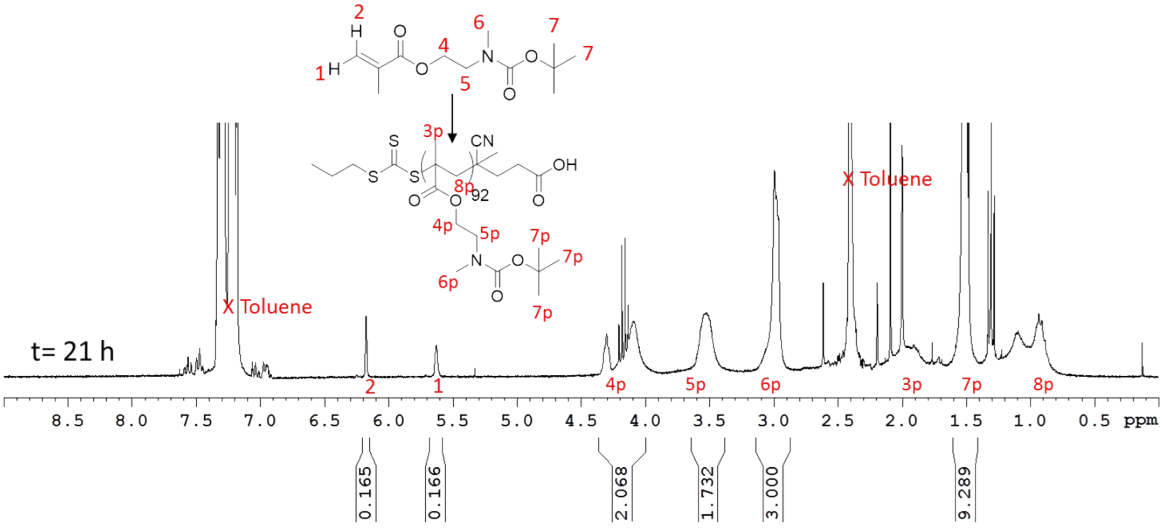


Figure S8. ^{1}H NMR spectra of pBMAEMA$_{92}$ polymerization at t=21 h. Conversion is 84%. (400 MHz, $CDCl_3$).

2.9. ^{1}H NMR spectra of pHEA$_{36}$

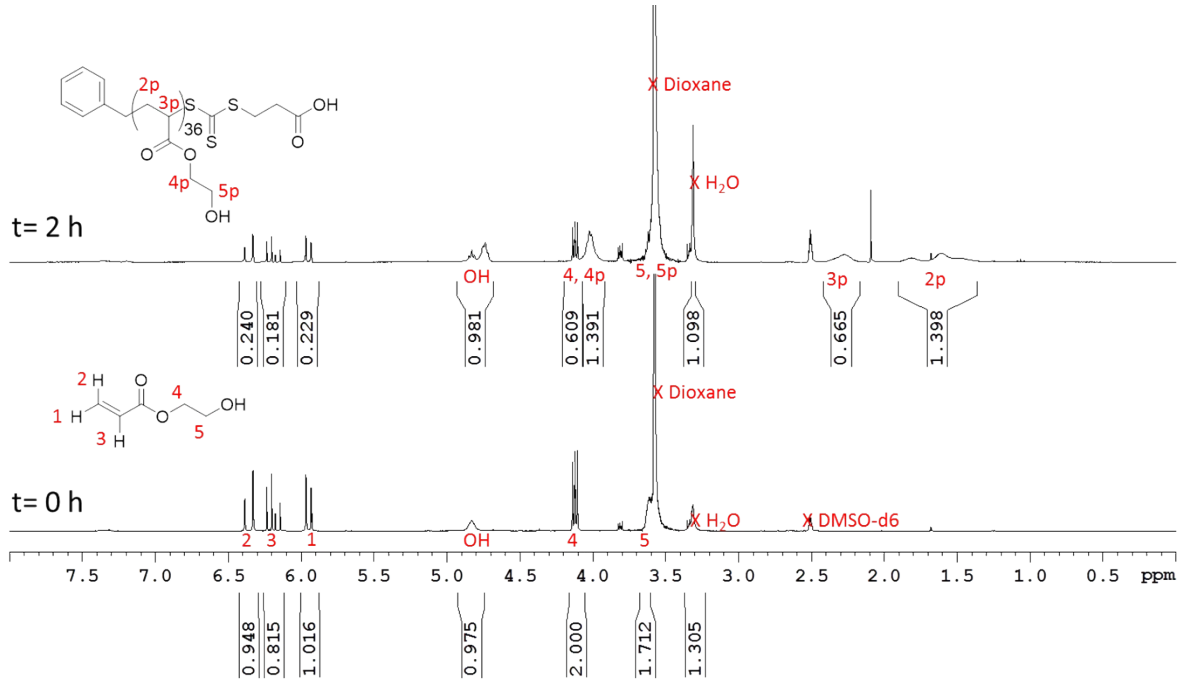


Figure S9. ^{1}H NMR spectra of poly(hydroxyethyl acrylate) (pHEA) homopolymer at t=2h. Conversion is 75%. (400 MHz, DMSO-d_6).

2.10. ^{1}H NMR spectra of pBMAEMA$_{29}$ chain extension with PEGMEMA

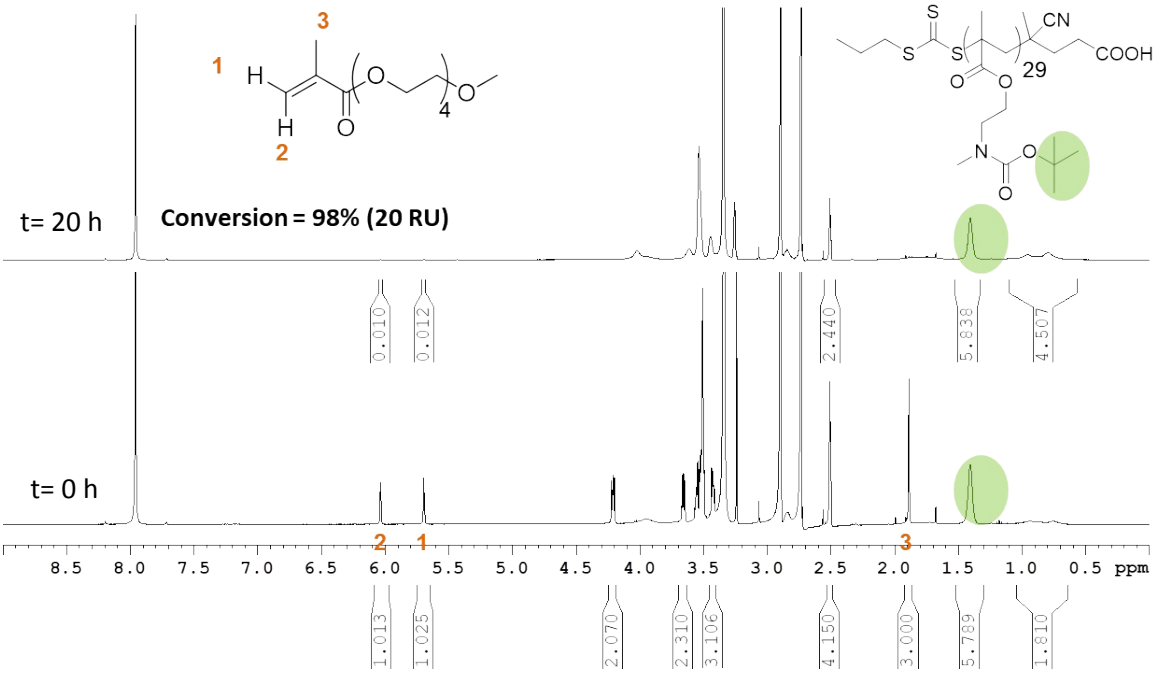


Figure S10. ^{1}H NMR spectra of crude block copolymer at t=0 and t=20 hours showing intact BOC groups of the pBMAEMA$_{29}$ units and 98% conversion of monomer (20 repeating units) (400 MHz, DMSO-d_6).

2.11. ^{1}H NMR spectra of pHEA$_{36}$ chain extension with BMAEA

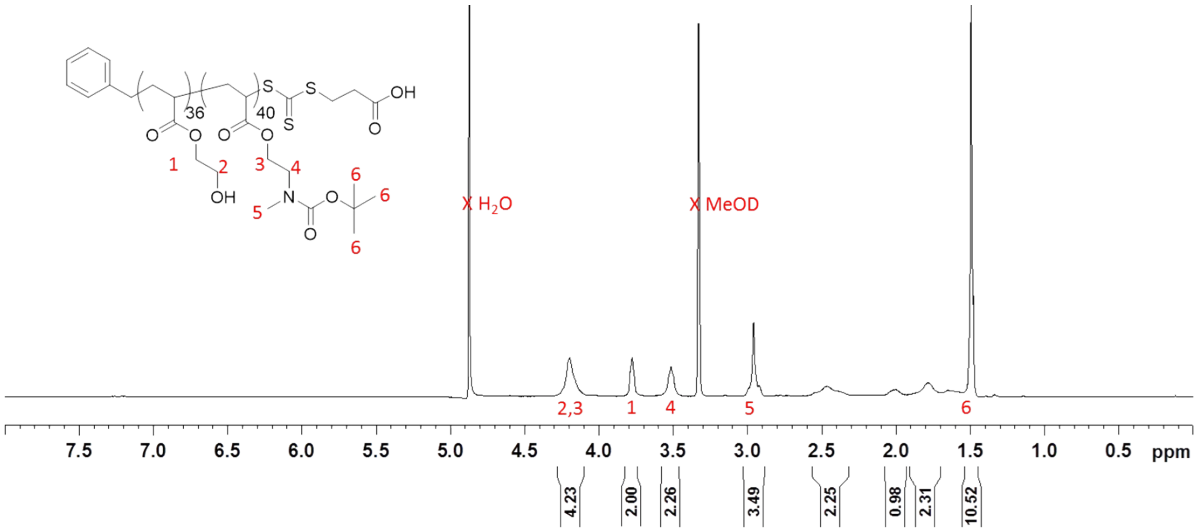


Figure S11. ^{1}H NMR spectra of pHEA$_{36}$-*b*-pBMAEA$_{40}$ block copolymer. (400 MHz, CD_3OD).

2.12. ^{1}H NMR spectra of deprotected BMAEAc

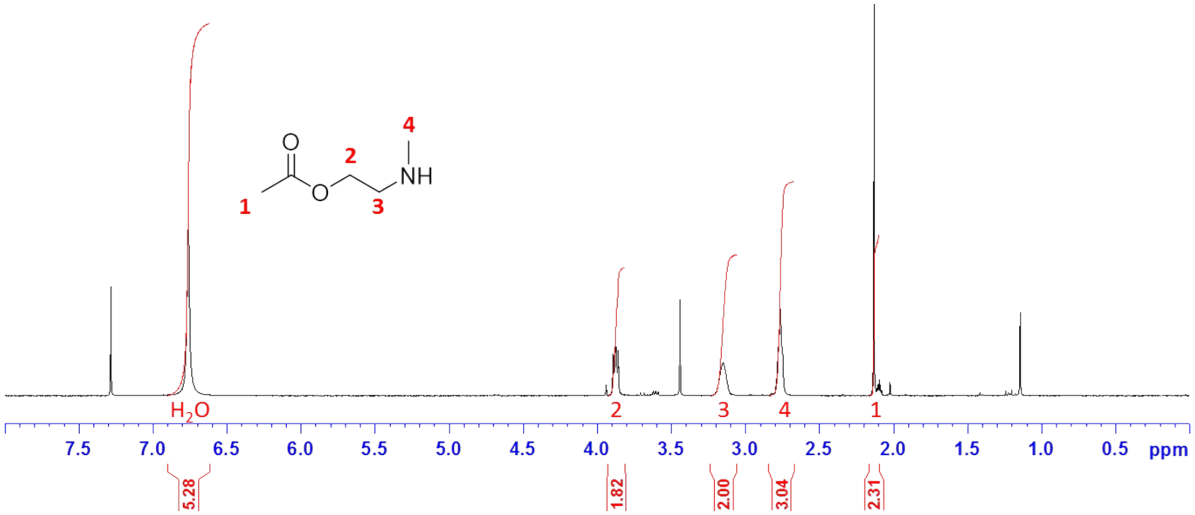


Figure S12. ^{1}H NMR spectra of MAEAc (400 MHz, $CDCl_3$).

2.13. ^{1}H NMR spectra of deprotected pBMAEA$_{23}$

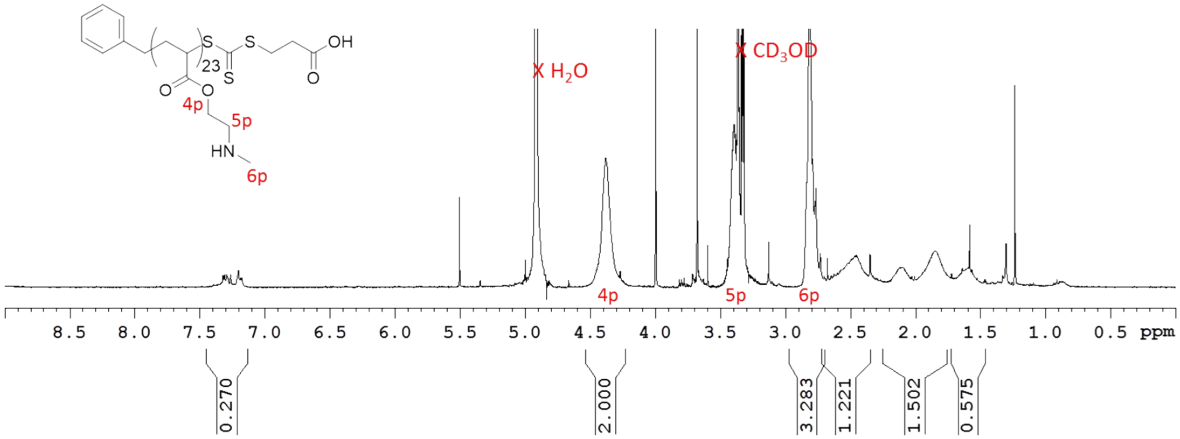


Figure S13. ^{1}H NMR spectra of pMAEA$_{23}$ (400 MHz, CD_3OD).

2.14. ^{1}H NMR spectra of deprotected pBMAEMA$_{101}$

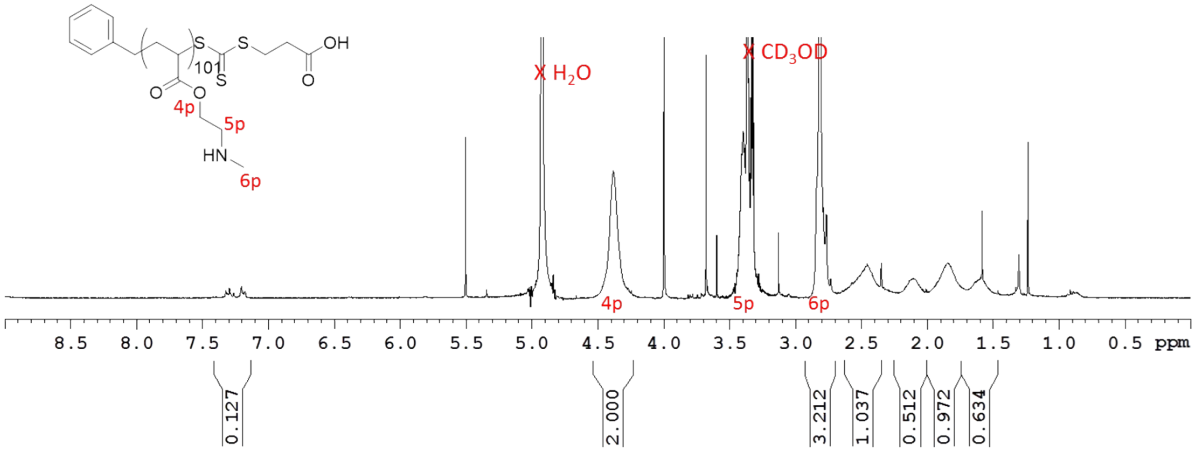


Figure S14. ^{1}H NMR spectra of pMAEA$_{101}$ (400 MHz, CD_3OD).

2.15. ^{1}H NMR spectra of deprotected pBMAEMA$_{29}$

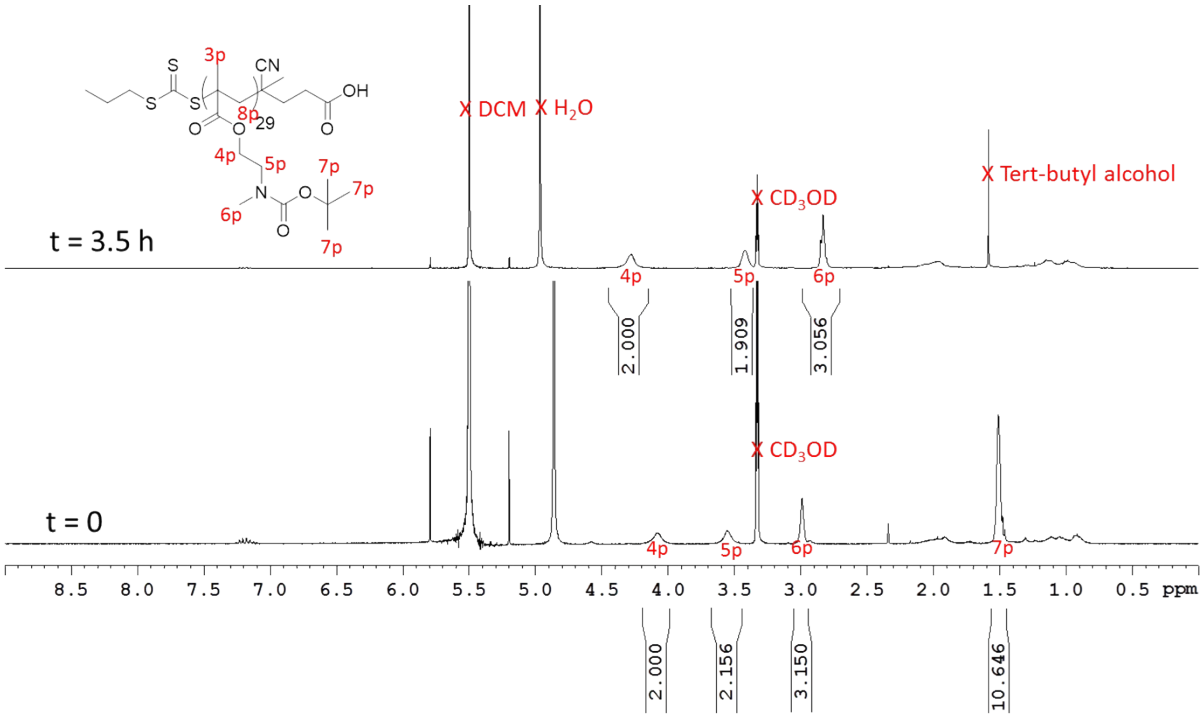


Figure S15. ^{1}H NMR spectra of crude pMAEMA$_{29}$ before (t=0) and after (t=3.5 h) deprotection (400 MHz, CD_3OD).

2.16. ^{1}H NMR spectra of deprotected pBMAEMA$_{92}$

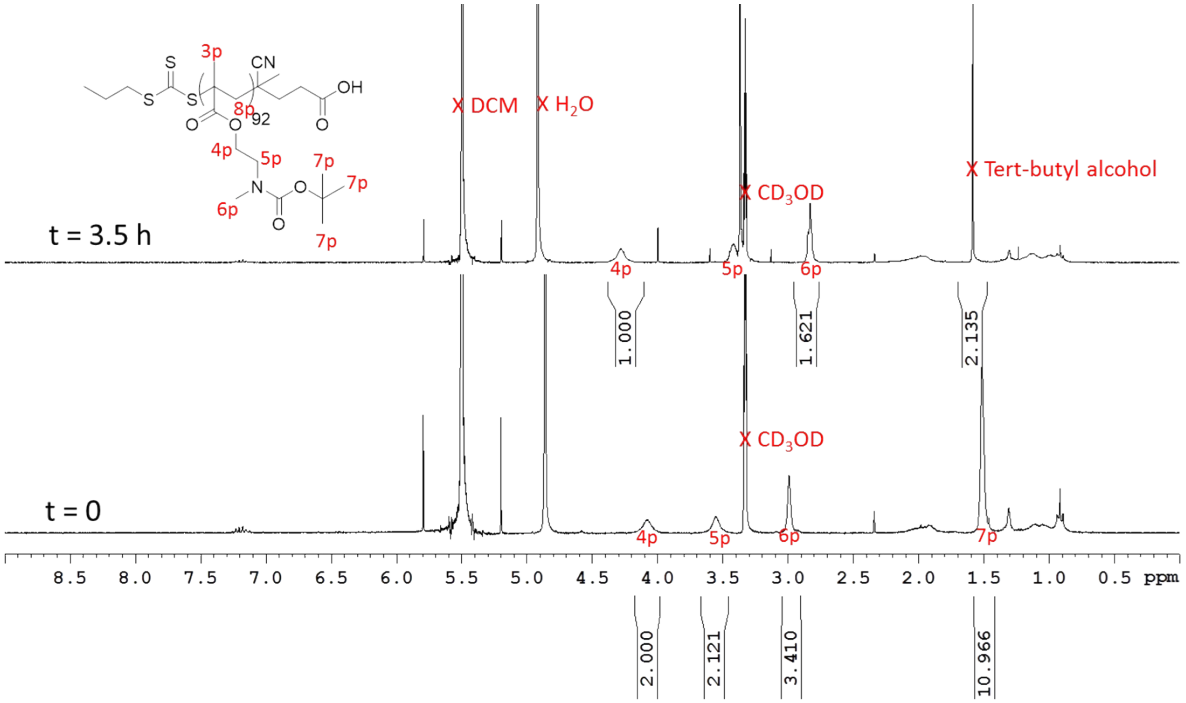


Figure S16. . ^{1}H NMR spectra of crude pMAEMA$_{92}$ before (t=0) and after (t=3.5 h) deprotection (400 MHz, CD_3OD).

2.17. ^{1}H NMR spectra of deprotected pHEA$_{36}$-*b*-pBMAEA$_{40}$

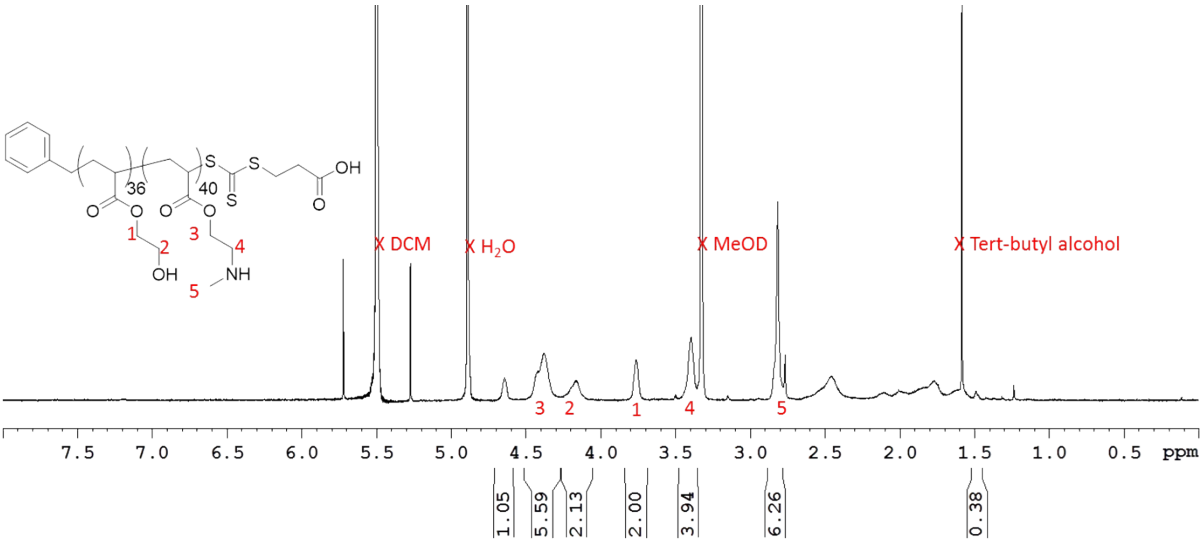


Figure S17. ^{1}H NMR spectra of pHEA$_{36}$-b-pMAEA$_{40}$ block copolymer. (400 MHz, CD_3OD).

2.18. ^{1}H NMR spectra of deprotected pBMAEMA$_{29}$-*b*-pPEGMEMA$_{20}$

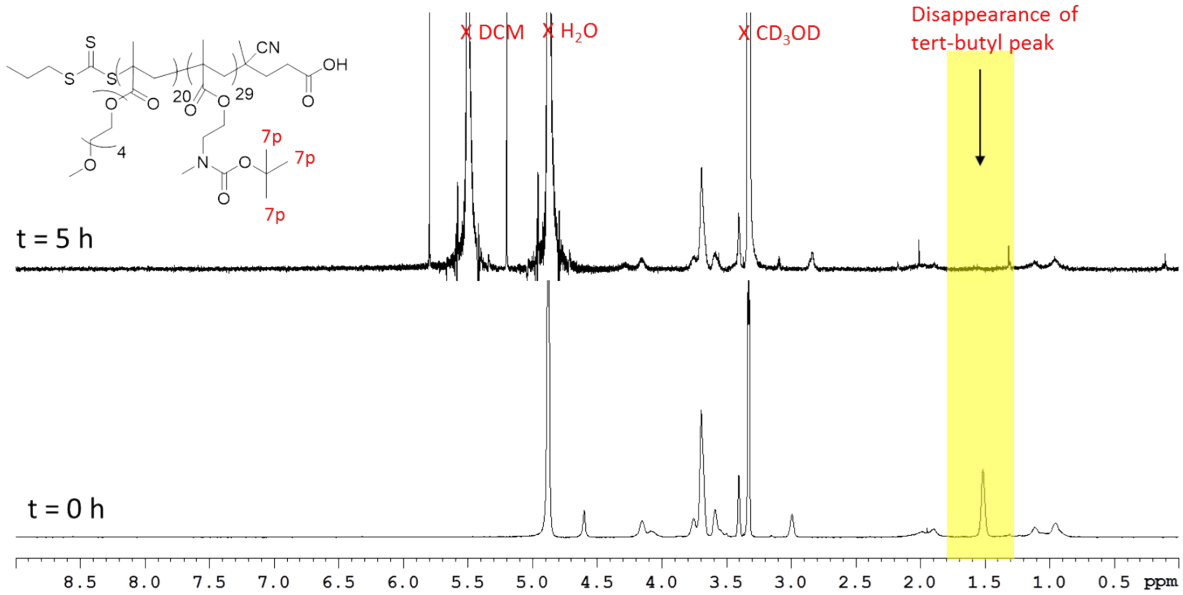
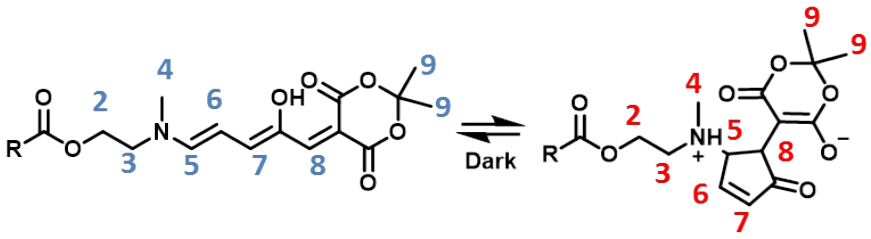


Figure S18. ^{1}H NMR spectra of crude pMAEMA$_{29}$-*b*-pPEGMEMA$_{20}$ block copolymer before (t=0) and after (t=3.5 h) deprotection (400 MHz, CD_3OD).

2.19. ^{1}H NMR spectra of MAEAc DASA (1) and calculation of isomer ratio

The DASA moiety in this study can be generalized as:



Scheme S1. DASA moiety in this study, R= CH_3, acrylate or methacrylate.

Where all proton signals are calculated by their integral. All DASA sample was measured with Bruker Avance III Cryo NMR (600 MHz) in DMSO-d_6, at 25°C. The samples were equilibrated in the solvent for 24 hours prior to measurement. For polymer DASA samples, the water signal (3.4 ppm) was suppressed to enhance the polymer peak (4.2 ppm). The relaxation time was increased to 20 seconds to increase the polymer peak intensity.

For the model DASA (MAEAc DASA, **1**) in Figure S19 as example, the conjugation efficiency (%) is:

$$DASA\ Conjugation\ (\%) = \left(\frac{\frac{Cyclic\ proton\ average\ (6+7)}{2} + \frac{Linear\ proton\ average\ (5+5') + (6+6') + (7+7') + (8+8')}{4}}{\frac{Polymer\ pendant\ group\ (2+2'+2)}{2}} \right) \times 100\%$$

$$DASA\ conjugation(\%) = \frac{\left(\frac{1.000 + 0.809}{2}\right) + \left(\frac{0.545 + 0.654 + 0.576 + 0.464}{4}\right)}{\frac{3.058}{2}} \times 100\%$$

$$= \frac{0.905 + 0.560}{1.529} \times 100\%$$

$$= 96\%$$

The ratio of the DASA isomer was calculated by:

$$Linear\ (\%) = \left(1 - \frac{\frac{Cyclic\ proton\ average\ (6+7)}{2}}{\frac{Cyclic\ proton\ average\ (6+7)}{2} + \frac{Linear\ proton\ average\ (5+5') + (6+6') + (7+7') + (8+8')}{4}} \right) \times 100\%$$

Thus, for the model DASA (MAEAc DASA, **1**) in Figure S19 the isomer ratio is:

$$Cyclic\ (\%) = \frac{\left(\frac{1.000 + 0.809}{2}\right)}{\left(\frac{1.000 + 0.809}{2}\right) + \left(\frac{0.545 + 0.654 + 0.576 + 0.464}{4}\right)} \times 100\%$$

$$= 62\%$$

$$\therefore Linear\ (\%) = 38\%$$

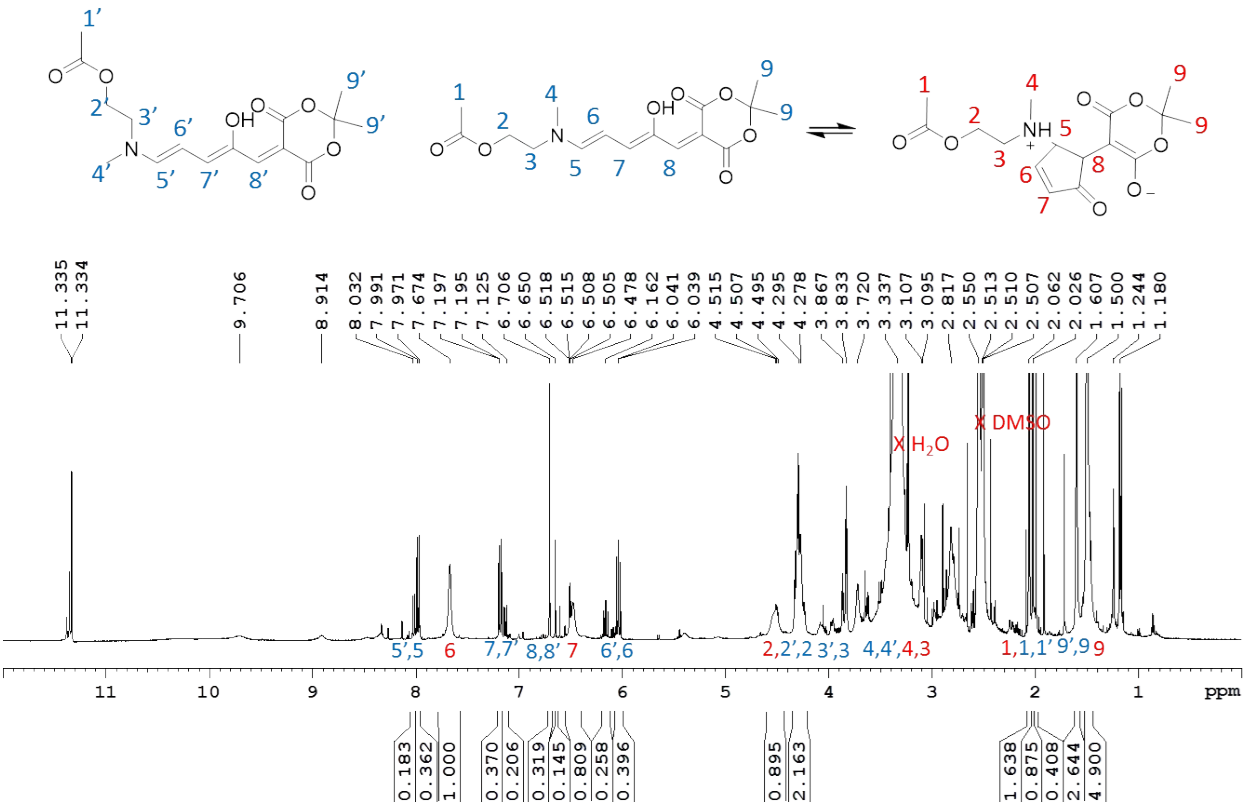


Figure S19. [1]H NMR spectra of **MAEAc** DASA, **1** (600 MHz, DMSO-d_6).

2.20. ^{1}H NMR spectra of pMAEA$_{23}$ DASA (2A)

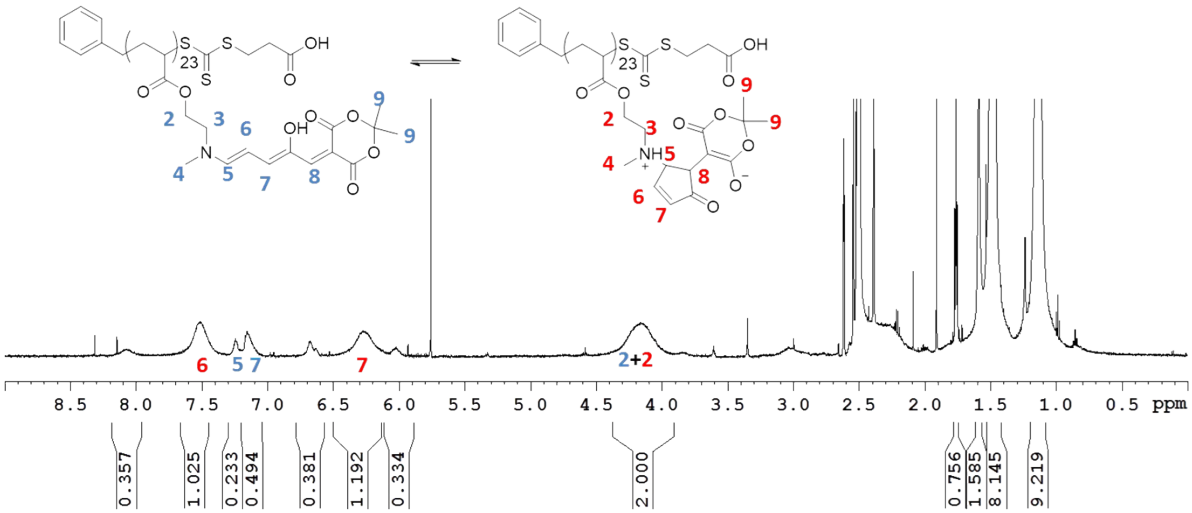


Figure S20. ^{1}H NMR spectra of pMAEA$_{23}$ DASA (600 MHz,DMSO-d_6).

2.21. ^{1}H NMR spectra of pMAEA$_{101}$ DASA (2B)

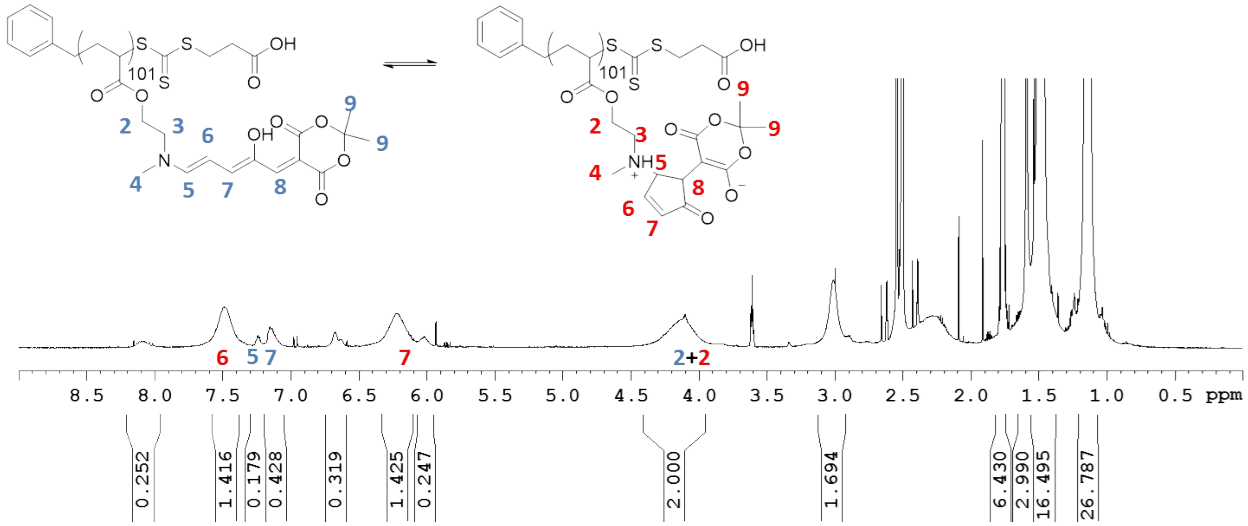


Figure S21. ^{1}H NMR spectra of pMAEA$_{101}$ DASA (600 MHz, DMSO-d_6).

2.22. ^{1}H NMR spectra of pMAEMA$_{29}$ DASA (3A)

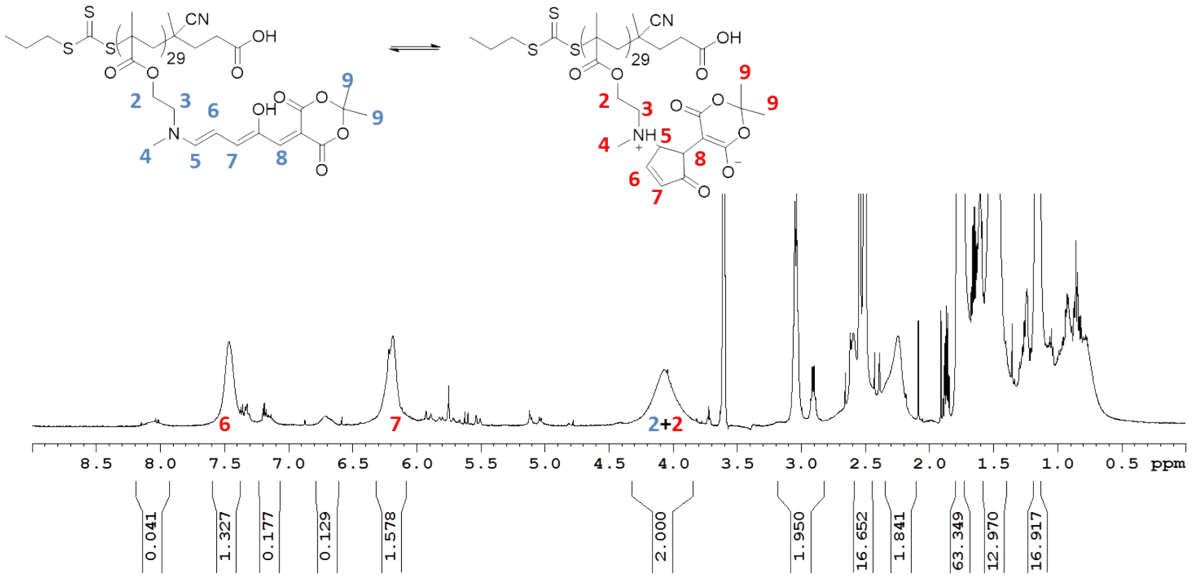


Figure S22. ^{1}H NMR spectra of pMAEMA$_{29}$ DASA (600 MHz, DMSO-d_6)

2.23. ^{1}H NMR spectra of pMAEMA$_{92}$ DASA (3B)

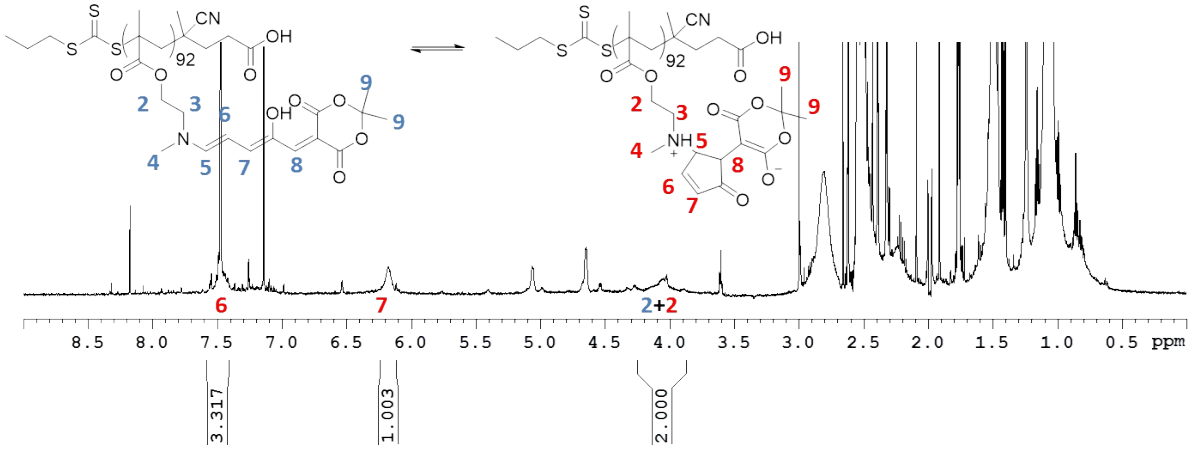


Figure S23. ^{1}H NMR spectra of pMAEMA$_{92}$ DASA (600 MHz, DMSO-d_6)

2.24. ^{1}H NMR spectra of pHEA$_{36}$-*b*-pMAEA$_{40}$ DASA

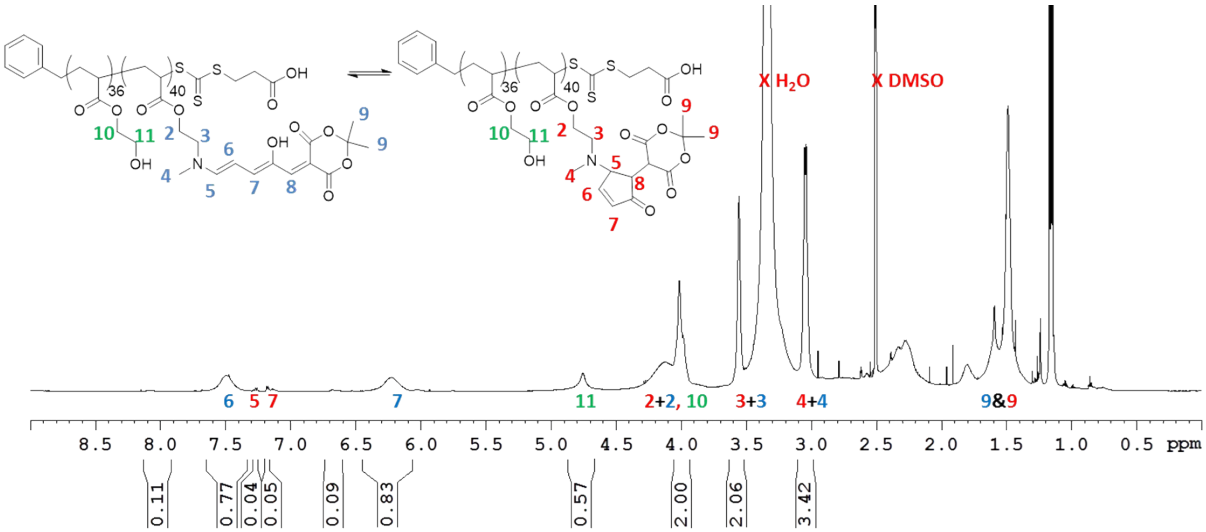


Figure S24. ^{1}H NMR spectra of pHEA$_{36}$-*b*-pMAEA$_{40}$ block copolymer conjugated with DASA. Conjugation is 67% after 24 hours at 25°C (600 MHz, DMSO-d_6).

2.25. ^{1}H NMR spectra of pMAEMA$_{29}$-*b*-pPEGMEMA$_{20}$ DASA (4)

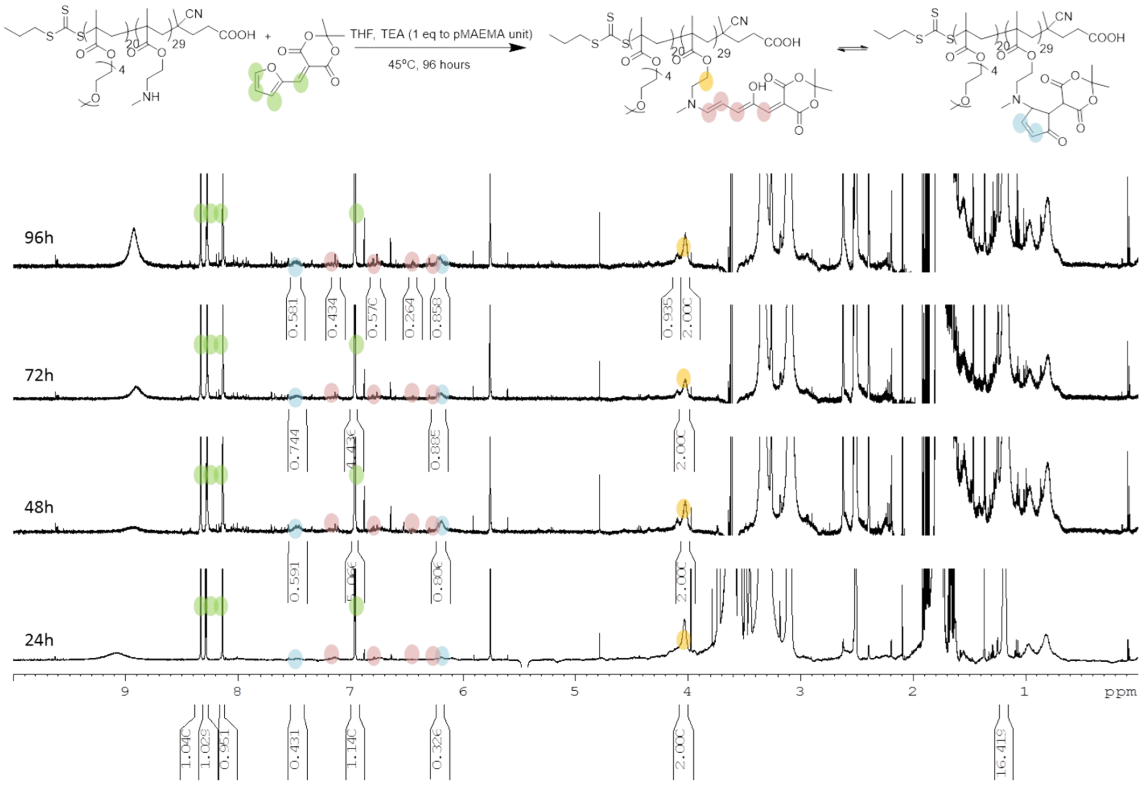


Figure S25. ^{1}H NMR spectra of crude solution of methacrylate DASA block copolymer from 24 – 96 hours. By comparing the integration of -CH$_2$-O- peak of the pMAEMA$_{29}$ at 4.1 ppm to the -CH- peak of cyclic DASA at 7.5 ppm and -CH- peak of linear DASA at 7.2 ppm shows that reaction has reached completion after 48 hours (600 MHz, DMSO-d_6).

2.26. ^{1}H NMR spectra of pMAEA$_{23}$ stability up to 2 months

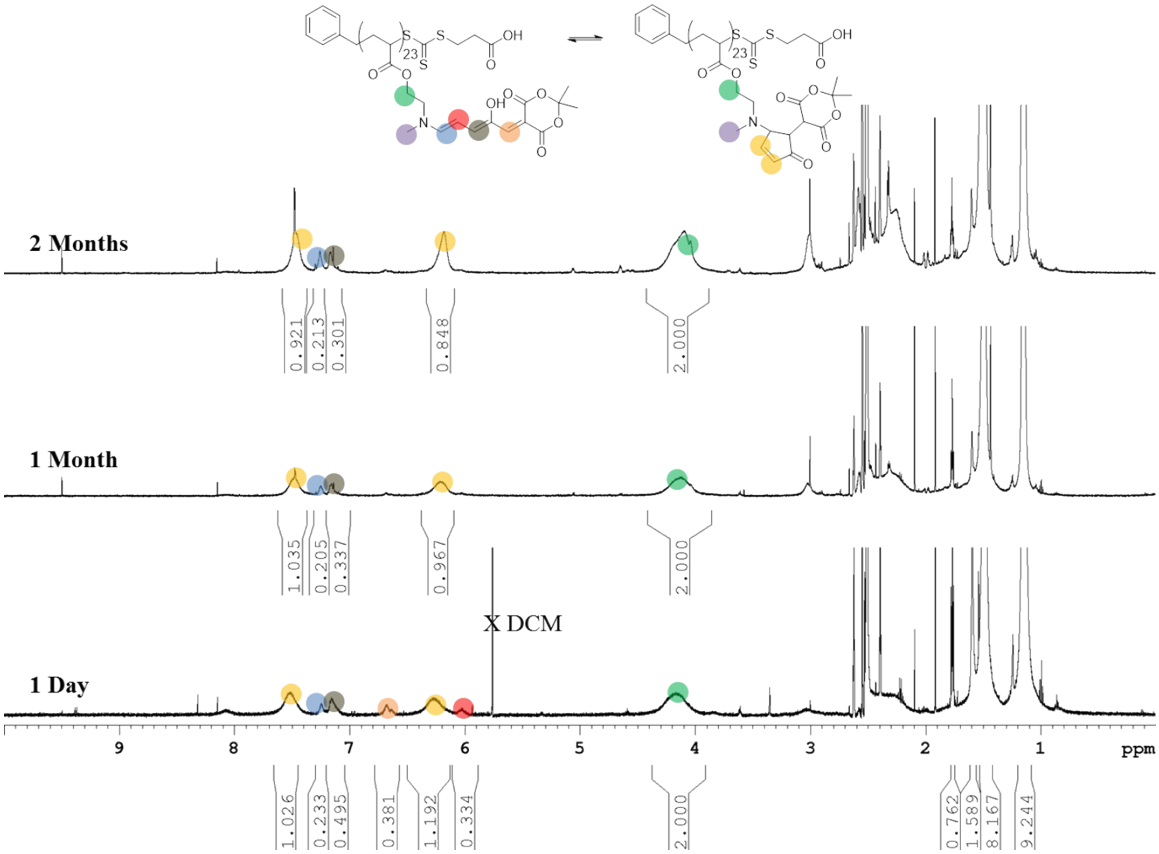


Figure S26. ^{1}H NMR spectra of pMAEA$_{23}$ DASA in DMSO-d_6 comparing the sample stability up to 2 months. The integration of both cyclic and isomer DASA (in yellow for cyclic, and blue, brown, orange and red for linear) is decreasing after 2 months of storage (600 MHz, DMSO-d_6).

2.27. ^{1}H NMR spectra of pMAEMA$_{29}$ stability up to 2 months

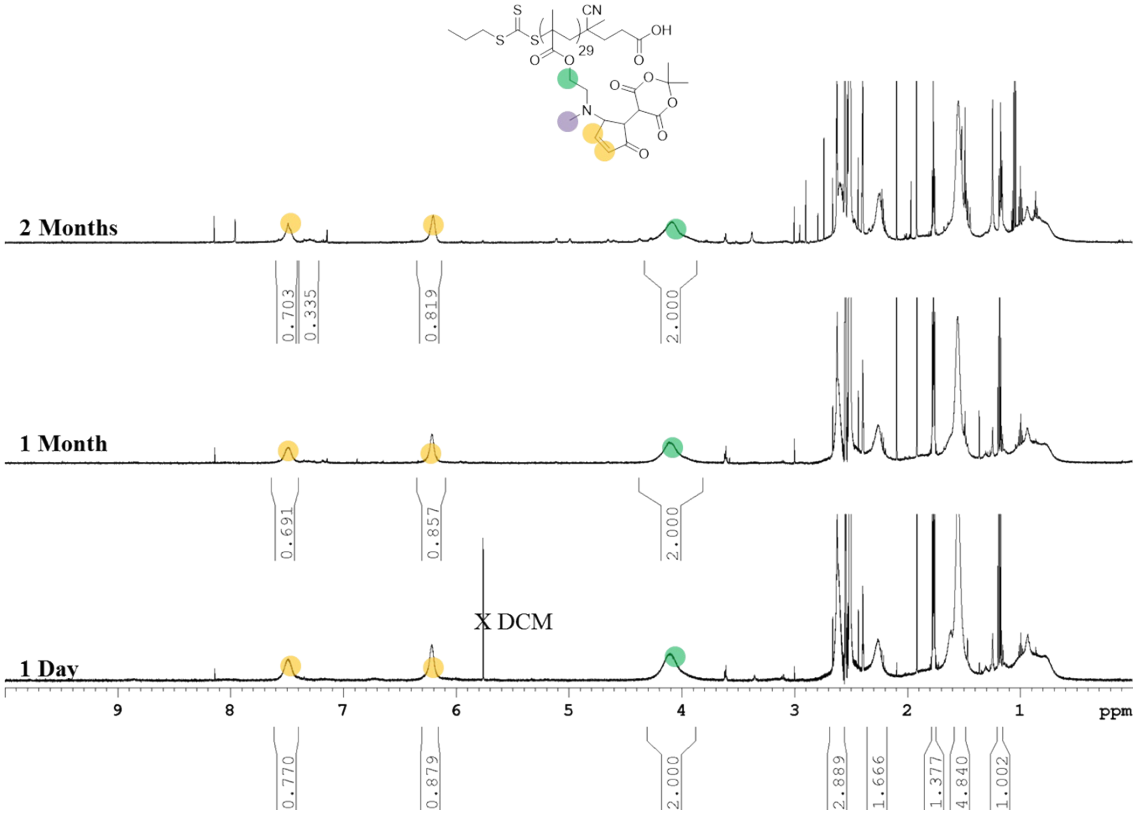


Figure S27. ^{1}H NMR spectra of pMAEMA$_{29}$ DASA in DMSO-d_6 comparing the sample stability up to 2 months. The integration of both cyclic and isomer DASA (in yellow for cyclic, and blue, brown, orange and red for linear) is stable after 2 months of storage (600 MHz, DMSO-d_6).

2.28. ^{1}H NMR spectra of pMAEA$_{23}$ stability in D_2O at pH 2, 7 and 11

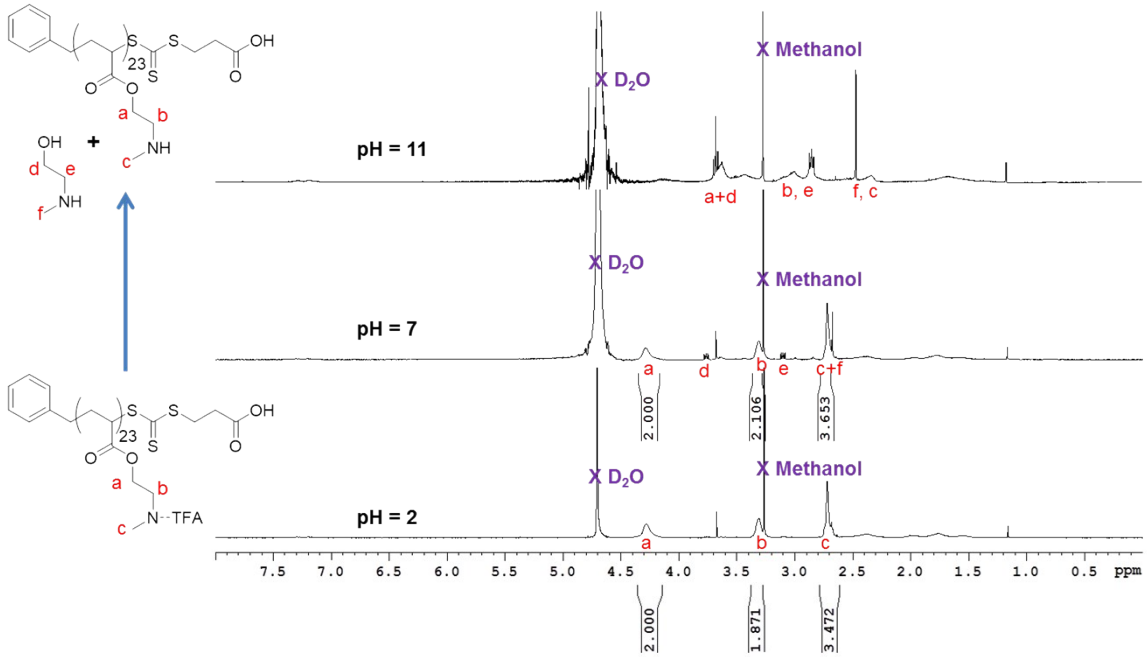


Figure S28. Deprotected acrylate polymer (pMAEA$_{23}$) in D_2O at pH 2, 7 and 11 measured after 24 hours. The pH was adjusted with addition of 0.25M and 0.025M aqueous NaOH solution. Small molecule formation at pH 7 and 11 (400 MHz, D_2O).

2.29. ^{1}H NMR spectra of pMAEMA$_{29}$ stability in D_2O at pH 2, 7 and 11

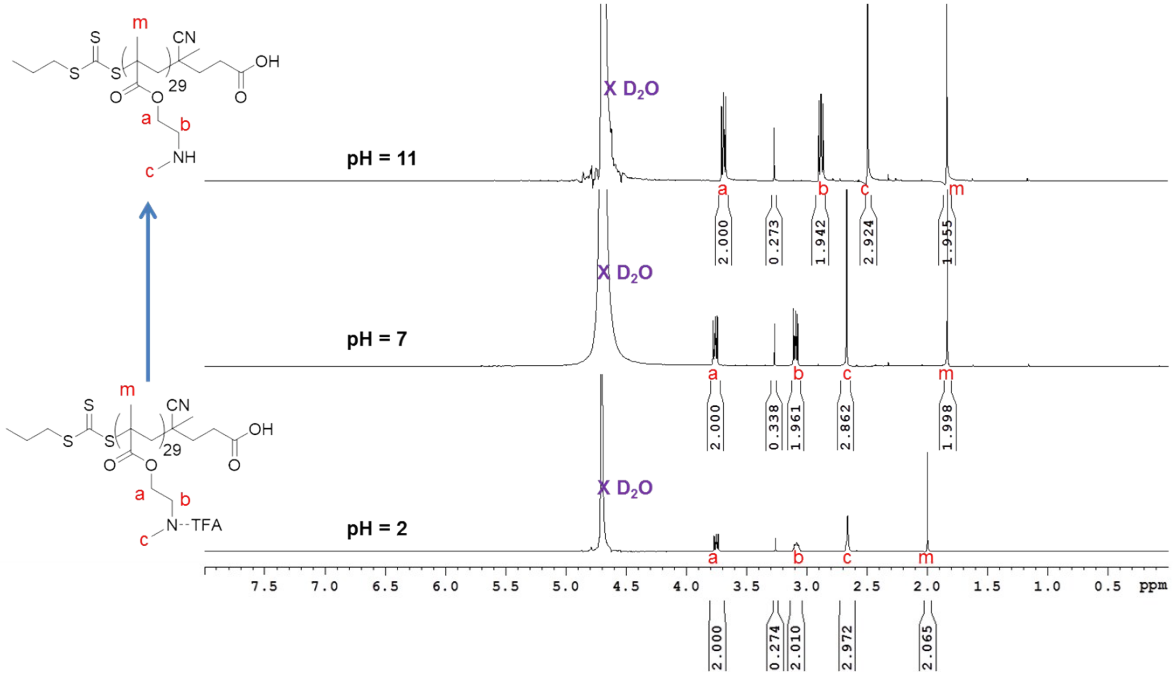


Figure S29. Deprotected methacrylate polymer (pMAEMA$_{29}$) in D_2O at pH 2, 7 and 11 measured after 24 hours. The pH was adjusted with addition of 0.25M and 0.025M aqueous NaOH solution (400 MHz, D_2O).

3. Size exclusion chromatography (SEC) characterisations

3.1. SEC trace of BOC protected homopolymers (DMF)

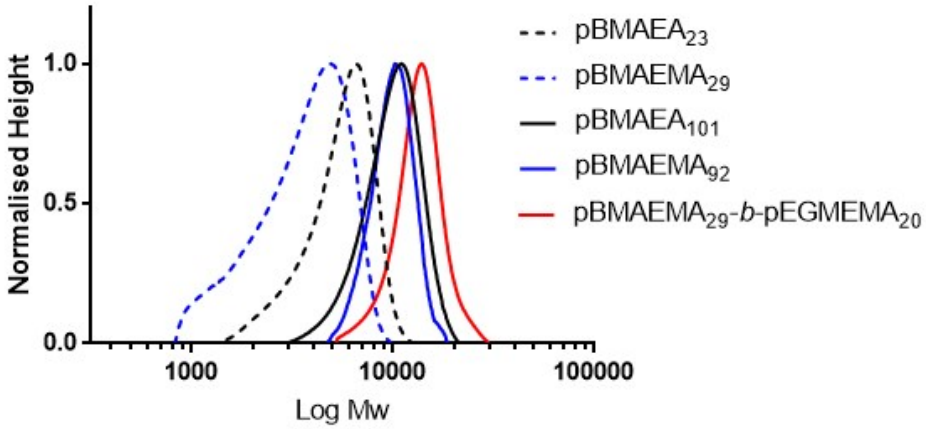


Figure S30. SEC trace of acrylate and methacrylate homopolymers as well as methacrylate block copolymer before deprotection. DMF was used as an eluent.

3.2. SEC trace homopolymer DASA (Water)

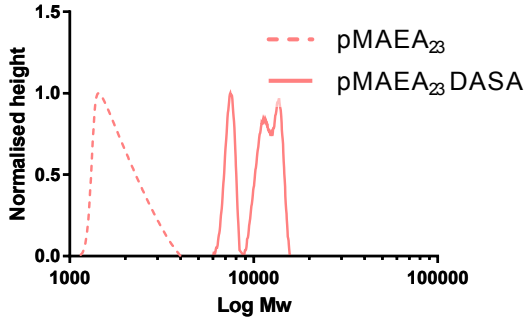


Figure S31. SEC trace of DASA **2A** before and after DASA conjugation. Water was used as an eluent.

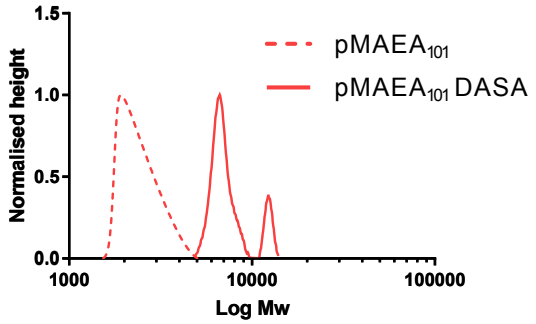


Figure S32. SEC trace of DASA **2B** before and after DASA conjugation. Water was used as an eluent.

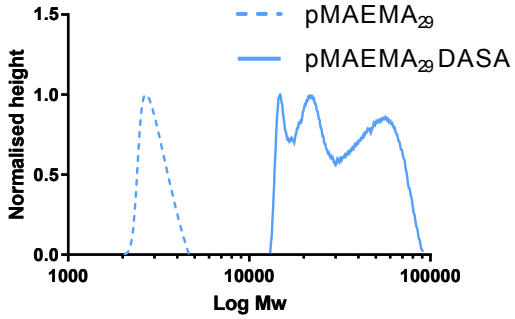


Figure S33. SEC trace of DASA **3A** before and after DASA conjugation. Water was used as an eluent.

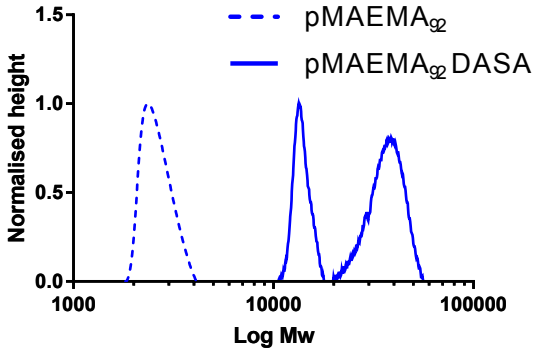


Figure S34. SEC trace of DASA **3B** before and after DASA conjugation. Water was used as an eluent.

3.3. SEC trace of acrylate block copolymer, 5 (DMF)

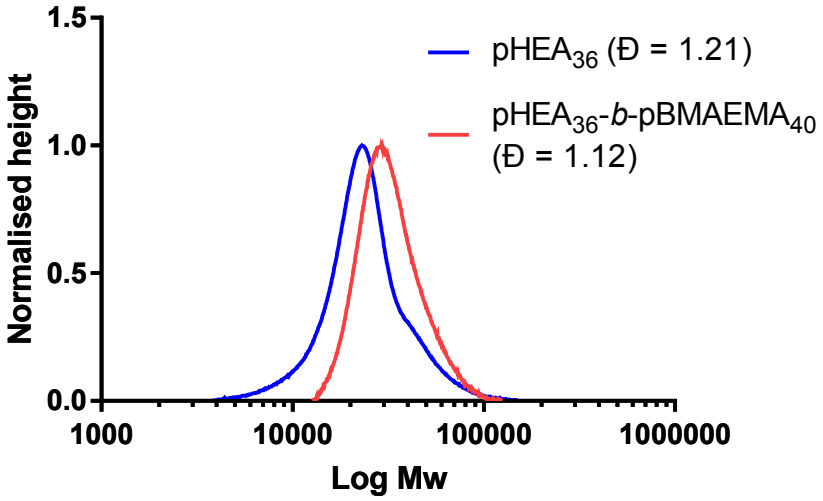


Figure S35. SEC trace of $pHEA_{36}$ homopolymer and $pHEA_{36}$-b-$pBMAEA_{40}$ block copolymer showing an increase of molecular weight (DMF).

4. Dynamic light scattering (DLS) characterisations

4.1. DLS results of acrylate DASA (5) micelles

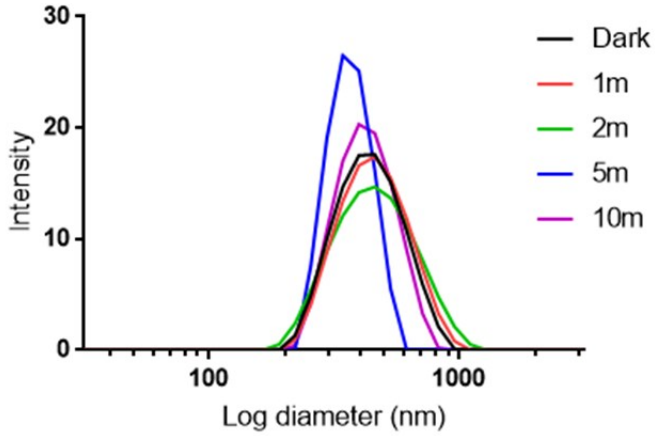


Figure S36. DLS Measurement of $pHEA_{36}$-*b*-$pMAEA_{40}$ DASA (**5**) micelles before (dark) and after 10 minutes irradiation (purple).

5. UV-vis switching experimental data and apparent half-life calculations

The half-life value was calculated by fitting the curve using an exponential regression analysis (performed in Origin software). The equation is shown below.

$$y = y_0 + Ae^{R_0 t}$$

Where y = absorbance, y_0= y offset, A= amplitude, R_0= rate constant and t = time in minutes. The apparent half-life times ($t_{1/2}$) were calculated as,

$$t_{1/2} = \frac{\ln 1/2}{R_0}$$

5.1. Solvatochromism of DASA model compound

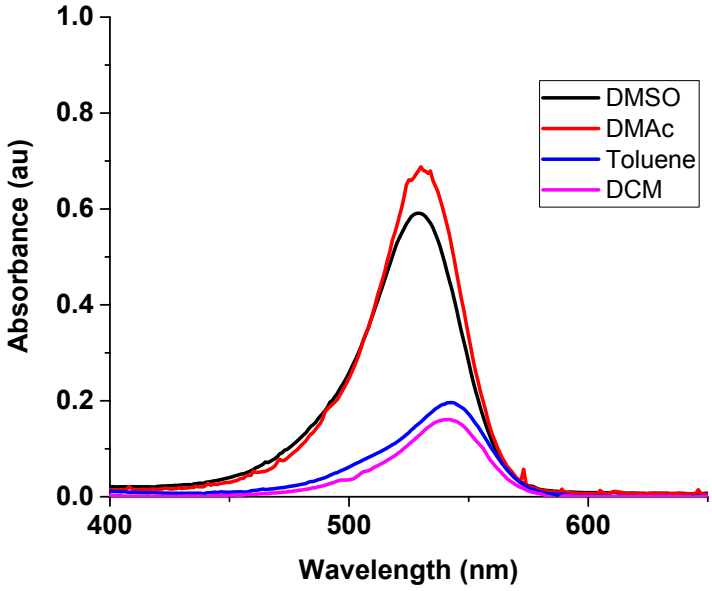


Figure S37. Negative solvatochromism of MAEAc DASA (**1**) showing a red shift from 530 nm in DMAc and DMSO to 543 nm in DCM and toluene.

5.2. UV-vis switching and apparent half-life calculation of MAEAc DASA (1) in toluene

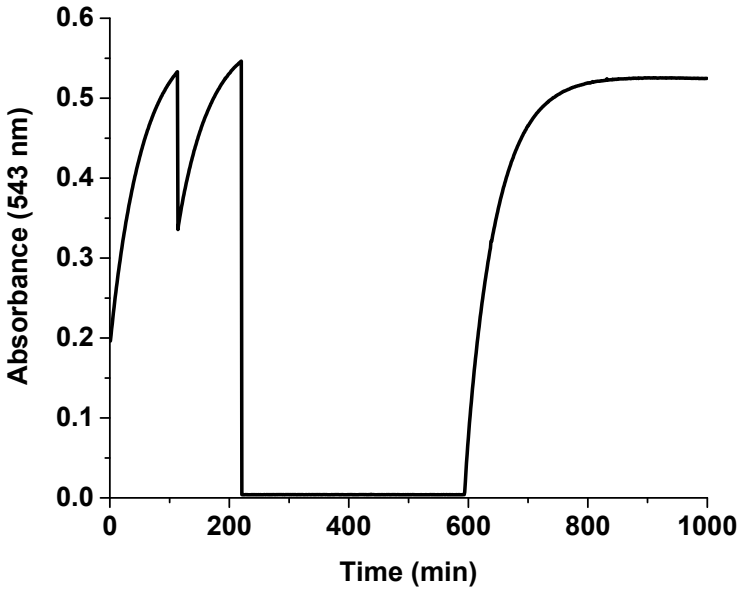


Figure S38. Switching of MAEAc DASA (**1**) in toluene. Green LED 530 nm, irradiation for 6 hours.

5.3. UV-vis switching and apparent half-life calculation of MAEAc DASA (1) in DCM

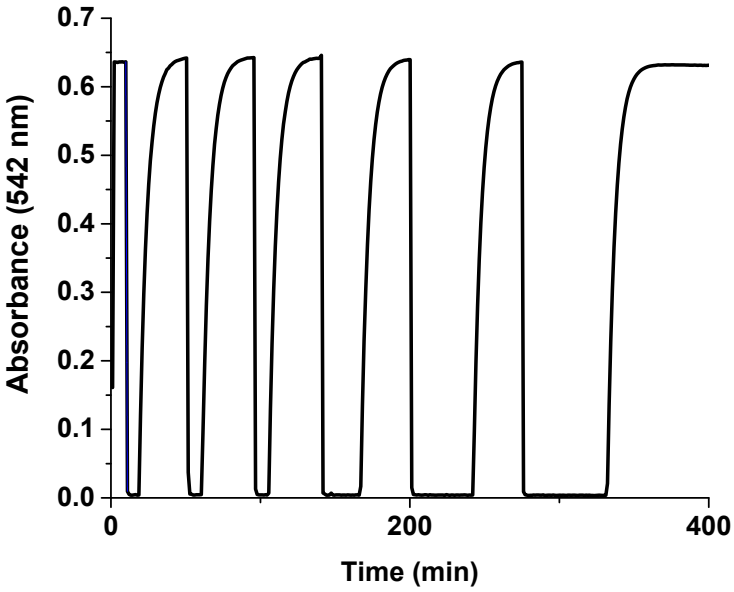


Figure S39. Switching of MAEAc DASA (**1**) in DCM. Green LED 530 nm, irradiation time incrementally increased from 5 minutes to 1 hour.

5.4. UV-vis measurement of thermal ring closing of MAEAc DASA (1) in DMAc

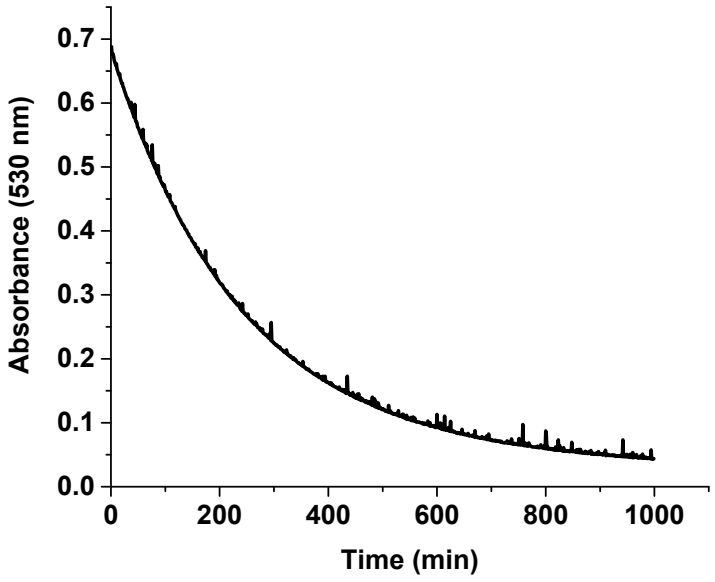


Figure S40. Thermal ring closing of MAEAc DASA (**1**) in DMAc in the dark.

5.5. UV-vis switching and apparent half-life calculation of MAEAc DASA (1) in DMSO

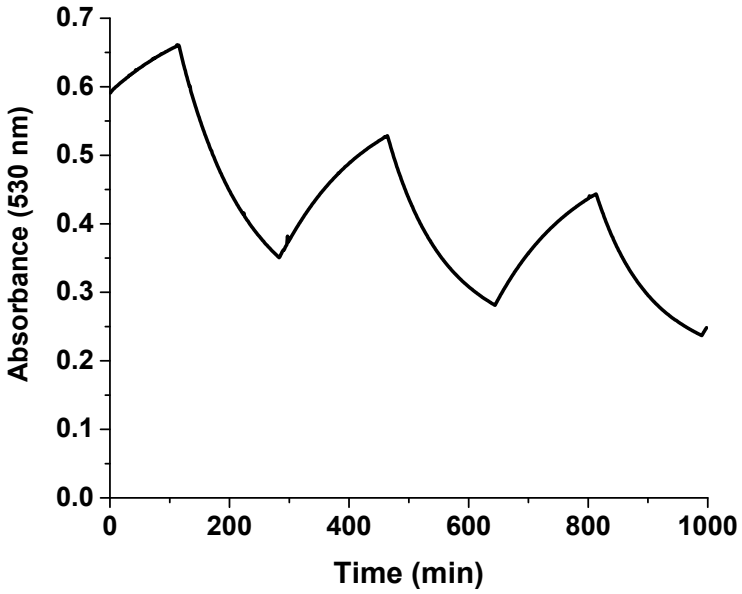


Figure S41. Switching of MAEAc DASA (**1**) in DMSO. Green LED 530 nm, irradiation for 3 hours and dark period for 2 hours.

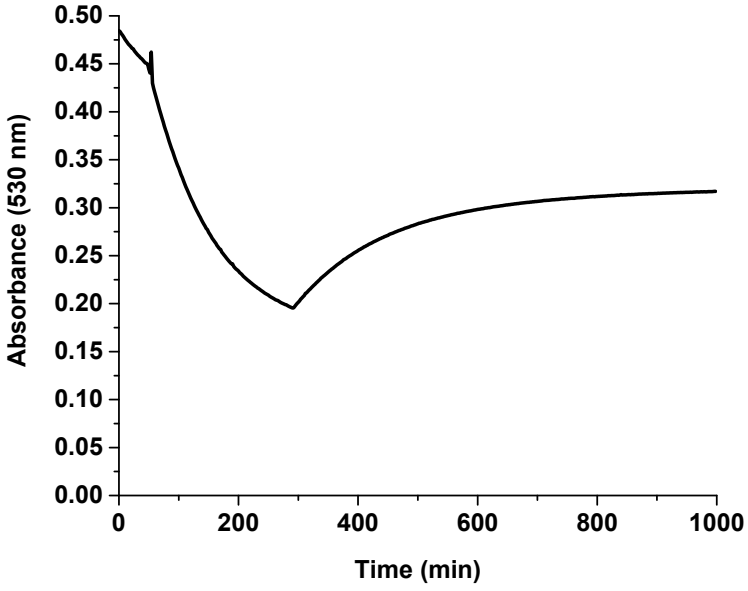


Figure S42. Switching of MAEAc DASA (**1**) in DMSO. Green LED 530 nm irradiation for 4 hours.

5.6. UV-vis measurement of MAEAc DASA (1) in water

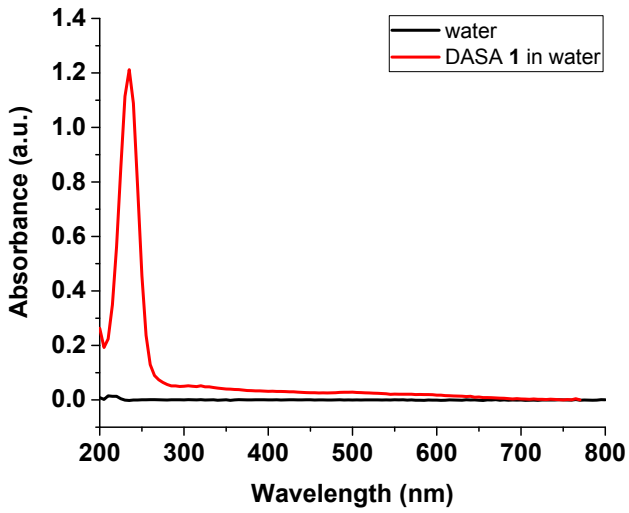


Figure S43. Absorbance measurement of MAEAc DASA (**1**) in MilliQ H_2O. No irradiation was performed, the sample has no absorbance in water.

5.7. UV-vis switching and apparent half-life calculation of pMAEMA$_{29}$ DASA (3A) in water

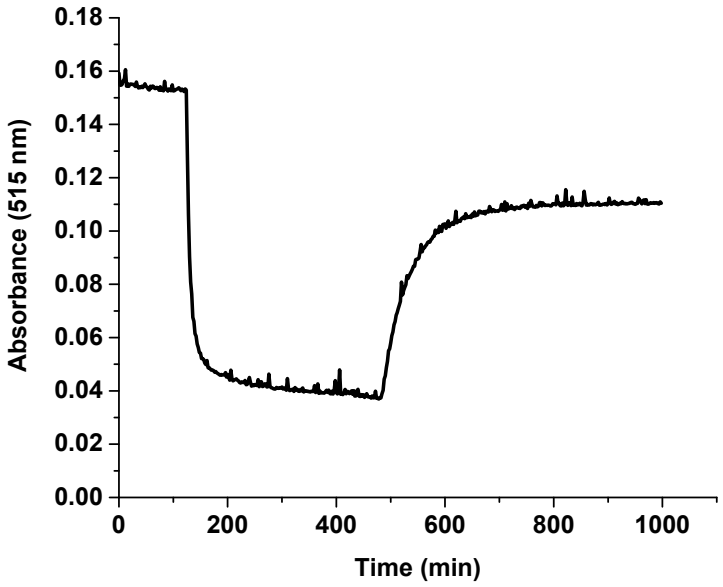


Figure S44. UV-Vis spectra of absorbance maxima of pMAEMA$_{29}$ DASA (**3A**) in MilliQ H_2O. Green LED (530 nm) irradiation for 6 hours.

5.8. UV-vis switching of $pHEA_{36}$-*b*-$pBMAEA_{40}$ DASA (5) micelles in water

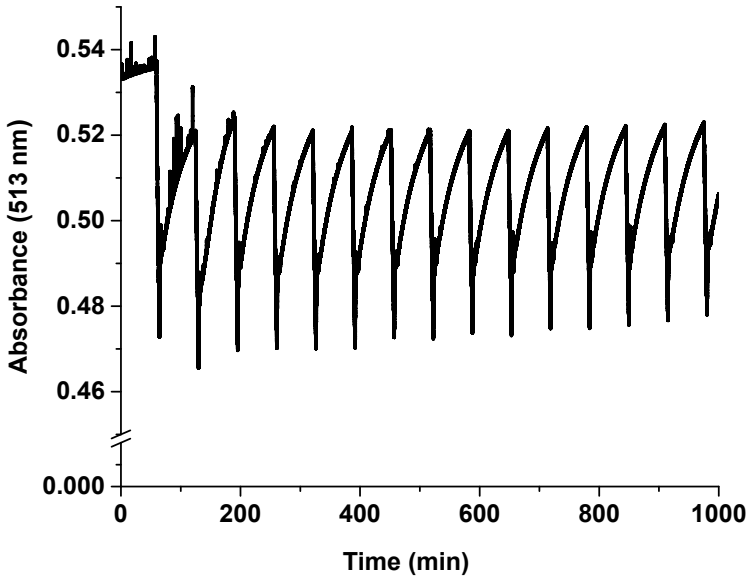


Figure S45. Switching experiment of $pHEA_{36}$-*b*-$pMAEA_{40}$ DASA (**5**) micelles in milliQ H_2O. Irradiation cycles were performed using green LED (530 nm) for 10 minutes followed by 1 hour of dark.

5.9. Calculated half lifetimes for DASA 1, and polymer DASA 2, 3 and 4

Table S2. Summary of calculated cyclisation half lifetimes for the model DASA and acrylate or methacrylate polymers functionalized with DASA units.[a]

Sample no.[b]	Sample Name	Solvent	Photostationary $t^p_{1/2}$[c] (minutes)	Recovery of λ_{max} $t^t_{1/2}$[d] (minutes)	ΔA[e] (%)	Recovery[f] (%)
1	MAEAc	Toluene	0.5	35	100%	95%
		DCM	0.6	4	100%	99%
		DMAc	N/A [h]	N/A [g]	93% [i]	N/A [g]
		DMSO	72	115	56%	67%
		Water	N/A	N/A	N/A	N/A
2A	$pMAEA_{23}$	DMSO	73	105	58%	56%
2B	$pMAEA_{101}$	DMSO	44	104	81%	41%
3A	$pMAEMA_{29}$	DMSO	21	103	61%	96%
		Water	8.6	37	73%	73%
3B	$pMAEMA_{92}$	DMSO	36	103	80%	56%
4	$pPEGMEMA_{20}$-*b*-$pMAEMA_{29}$	Water	28	67	60%	83%

[a] During irradiation and recovery cycles. [b] Sample number, see Scheme 1 for structures and Table 2 for polymer information. [c] Apparent half lifetimes to reach the photostationary state. [d] Apparent half lifetimes to reach equilibrium in the dark, see ESI 5 for calculation details. [e] Change in absorption at λ_{max} (ΔA) measured by UV-vis on samples irradiated with 530 nm LED until no change in absorption was observed. Initial absorbance were normalized to A = 1. [f] Recovery of absorption after irradiation for 6 hours with a 530 nm LED calculated from

the remaining absorption after dark period for 6 hours. Initial absorbance were normalized to A = 1. [g] N/A means no switching. The sample in DMAc solvent equilibrated to zero absorption in the dark (see Figure S40). [h] The sample equilibrated towards cyclic isomer in 16 hours in the dark without any irradiation. [i] After 17 hours in the dark the absorbance has equilibrated to a 93% reduction in color from original absorbance.

Table S3. Calculated photostationary half-life and recovery half-life for methacrylate DASA polymer **3A** at different solution concentrations.

Polymer (3A) concentration (mg/ml)	**Molar concentration**	**Photostationary $t^{p}_{1/2}$ [a] (minutes)**	**Recovery $t^{t}_{1/2}$ [b] (minutes)**
0.83	7.63×10^{-5} M	19	259
0.277	2.54×10^{-5} M	17.6	139
0.166	1.52×10^{-5} M	19.5	134

[a]Apparent half lifetimes to reach the photostationary state. [b] Apparent half lifetimes to reach equilibrium in the dark, see ESI 5 for calculation details.

6. Solubility studies

6.1. Solubility of DASA model (1)

Table S4. Solubility table of the model DASA (**1**) before and after irradiation and its switching ability compared with the solubility of methacrylate DASA polymer (**3A**).[a]

Solvent	MAEAc DASA model (1) solubility		Methacrylate DASA polymer (3A) solubility
	Before irradiation	After irradiation	Before irradiation
Water	✓	✓	✓
Chloroform	✓	✓	partial
Dichloromethane	✓	✓	partial
Dimethylsulfoxide	✓	✓	✓
1,4-Dioxane	✓	✓	×
Ethanol	✓	✓	×
Methanol	✓	✓	partial
Diethyl ether	✓	✓	×
n-Hexane	×	×	×
Tetrahydrofuran	partial	partial	×
Ethyl acetate	✓	✓	×
Toluene	✓	✓	×
Dimethylformamide	✓	✓	✓
Dimethylacetamide	✓	✓	✓
Acetonitrile	✓	✓	partial

[a] Irradiation with 530 nm LED, 5 minutes irradiation, 2.15 W intensity.

The model DASA dissolves in most solvents but it switches faster in some solvents such as chloroform, DCM, toluene, diethyl ether, ethyl acetate and dioxane. Switching data for the model DASA in different solvents in shown in Table 2 and ESI, Figure S38-S43, which serve as a reference for the later data with polymers. The absorption maxima depend on the solvent, with the more polar solvents such as DMSO and DMAc causing a blue shift relative to non-polar solvents (ESI, Figure S37).

7. References

(1) Feldermann, A.; Stenzel, M. H.; Davis, T. P.; Vana, P.; Barner-Kowollik, C. *Macromolecules* 2004, **37**, 2404–2410.

(2) Xu, X.; Smith, A. E.; Kirkland, S. E.; McCormick, C. L. *Macromolecules* 2008, **41**, 8429–8435.