ELECTRONIC SUPPORTING INFORMATION

Pentablock star shaped polymers in less than 90 minutes via aqueous SET-LRP

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Table of contents:

1. Materials

N-Isopropylacrylamide (NIPAM, 97%) was recrystallized from *n*-Hexane and stored at 4 °C. 2-Hydroxyethyl acrylamide (HEAm, 97%) and *N,N*-Dimethylacrylamide (DMA, 99%) were passed over a short column of basic aluminium oxide to remove the inhibitor prior to use. Glycerol ethoxylate ($M_n \approx 1000$ g/mol), α-Bromoisobutyryl bromide (BIBB, 98%) and Triethylamine (TEA, ≥99%) were purchased from Sigma-Aldrich and used as received. All other chemicals and solvents were purchased from Sigma-Aldrich (UK) at the highest purity available and used as received unless stated otherwise.

Used for the disproportionation and reaction solvent; water (H_2O, HiPerSolv Chromanorm for HPLC) was purchased from VWR International (UK).

Tris(2-(dimethylamino)ethyl)amine (Me_6TREN) was synthesized according to literature procedures and stored at 4°C prior to use.[1,2]

Copper(I) bromide (CuBr, 98%, Sigma-Aldrich) was purified by stirring in acetic acid overnight and washing with copious amounts of ethanol before drying under vacuum to constant weight.[3]

2. Instruments and analysis

Proton nuclear magnetic resonance (^{1}H NMR) spectra were recorded on a Bruker AV-III 400 using D_2O at 303 K unless stated otherwise. Full monomer conversion was shown by the disappearance of the vinyl protons (H_2C=CH-CO–) (≈6.5-5.5 ppm). Otherwise, monomer conversion for NIPAM, HEAm and DMA was determined, comparing the integral of vinyl protons with isopropyl (–CH(CH_3)$_2$) (≈3.90-3.50 ppm), ethyl (NH(–CH_2–) (≈3.3 ppm) and dimethyl protons (–N(CH_3)$_2$) (≈3.0 ppm) respectively. All samples taken were immediately diluted with D_2O for analysis.

Gel permeation chromatography (GPC) measurements were conducted on an Agilent 1260 infinity system operating in DMF with 5mM NH_4BF_4 and equipped with refractive index detector and variable wavelength detector, 2 PLgel 5 μm mixed-C columns (300×7.5mm), a PLgel 5 mm guard column (50x7.5mm) and an autosampler. The instrument was calibrated with linear narrow poly(methyl methacrylate) standards in range of 550 to 46890 g/mol. All samples were passed through neutral aluminium oxide to remove any catalyst residues and filtered with a 0.2 μm Nylon 66 before analysis.

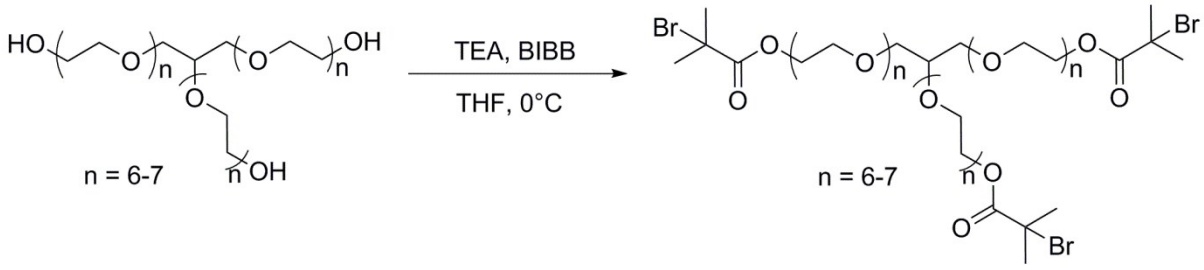
Turbidity measurements were performed on a Cary 100 UV-Vis spectrophotometer (Agilent) at a wavelength of 500 nm. Solutions of polymers were prepared in water (HPLC grade) at a concentration of 1 mg mL^{-1} and stirred until fully dissolved. The samples were thermostatted at 20 °C for 15 minutes prior to measurement. The transmittance was measured between 20 °C and 80 °C at a rate of 1 °C min^{-1} in a heating and cooling cycle. The cloud points reported were determined as the 50% transmittance point during the heating cycle.

Matrix assisted laser desorption/ionisation – time of flight mass spectroscopy (MALDI-TOF MS) was performed using a Bruker Daltonics Autoflex MALDI-ToF mass spectrometer, equipped with a nitrogen laser at 337 nm with positive ion ToF detection. Polymer samples were measured as follows; solutions in THF of trans-2-[3-(4-*tert*-Butylphenyl)-2-methyl-2-propenylidene]malononitrile (DCTB, ≥98%) as matrix (30 mg·mL^{-1}), potassium trifluoroacetate (KTFA) as cationisation agent (10 mg·mL^{-1}) and sample (10 mg·mL^{-1}) were mixed together in a 9:1:1 volume ratio for a total volume of 75 μL. 2 μL of the mixture was applied to the target plate. Spectra were recorded in reflectron mode and the mass spectrometer was calibrated with a peptide mixture up to 6000 Da.

All reactions were carried out using standard Schlenk techniques under inert atmosphere of oxygen-free argon.

3. Synthesis

3.1 Synthesis of the water soluble star initiator (Gly-Br_3)

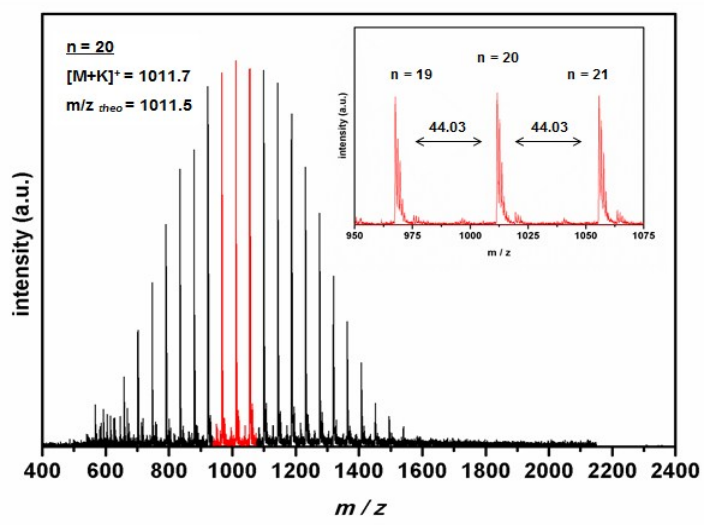


Glycerol ethoxylate — Glycerol ethoxylate initiator (**Gly-Br3**)

In a round bottom flask, glycerol ethoxylate (26.4 mL) and TEA (22.35 mL) were stirred in dry THF (250 mL) and cooled down to 0°C in an ice-bath. A mixture of BIBB (16.7 mL) and THF (50 mL) were added dropwise over a period of 1 hour under argon. The mixture was then allowed to warm up to ambient temperature and stirred overnight. The precipitated salt was removed *via* filtration and washed with 30 mL of THF. The filtrate was collected an concentrated *in vacuo*, precipitated twice in hexane, dissolved in DCM and passed over a column of basic aluminium oxide to remove any impurities to yield a viscous off-white oil. (**Yield** = 29.0 mL, 78%)

$M_{n,MALDI}$ = 1456,1 Da, calculated for $[C_{55}H_{103}O_{26}Br_3+K^+]$ = 1455.392 Da.
$M_{n,GPC}$ = 1900 $gmol^{-1}$, (PDi = 1.04).
^{1}H NMR ($CDCl_3$, 400 MHz) δ: 4.32 (t, 6H), 3.76-3.71 (m, 7H), 3.69-3.58 (broad, 72H), 3.58-3.48 (m, 4H), 1.96 (s, 18H) ppm.
^{13}C NMR ($CDCl_3$, 400 MHz) δ: 171.49, 78.30, 70.90-70.34, 68.65, 65.02, 55.62, 30.67 ppm.

A



B

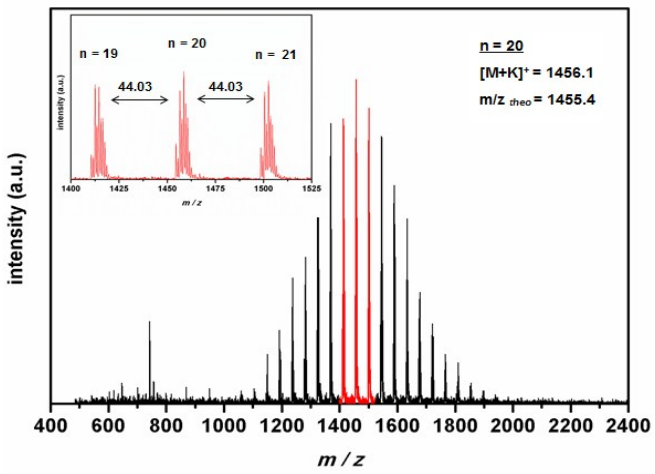
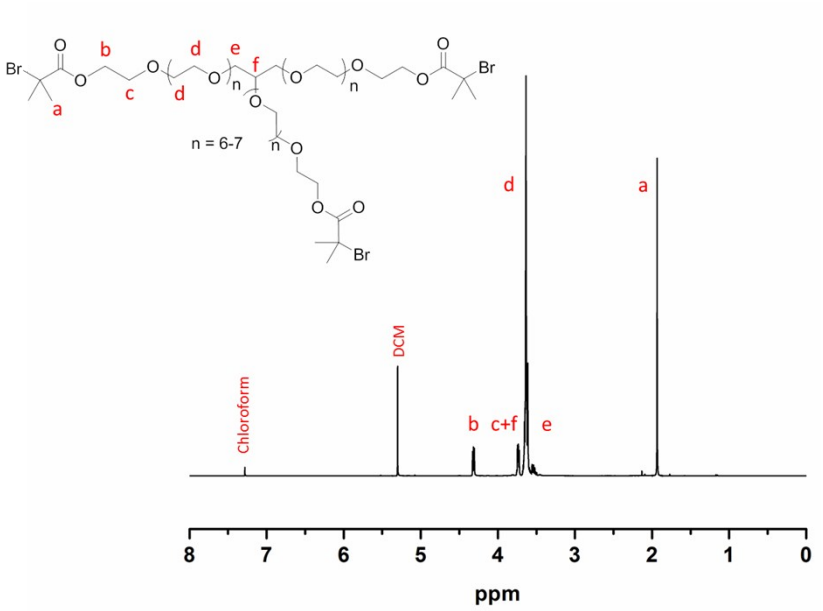


Figure S1: MALDI-ToF MS spectra of glycerol ethoxylate **(A)** and star initiator **Gly-Br$_3$ (B)** displaying corresponding increase in *m/z* due to esterification of the hydroxy-groups and change in isotopic pattern.

A



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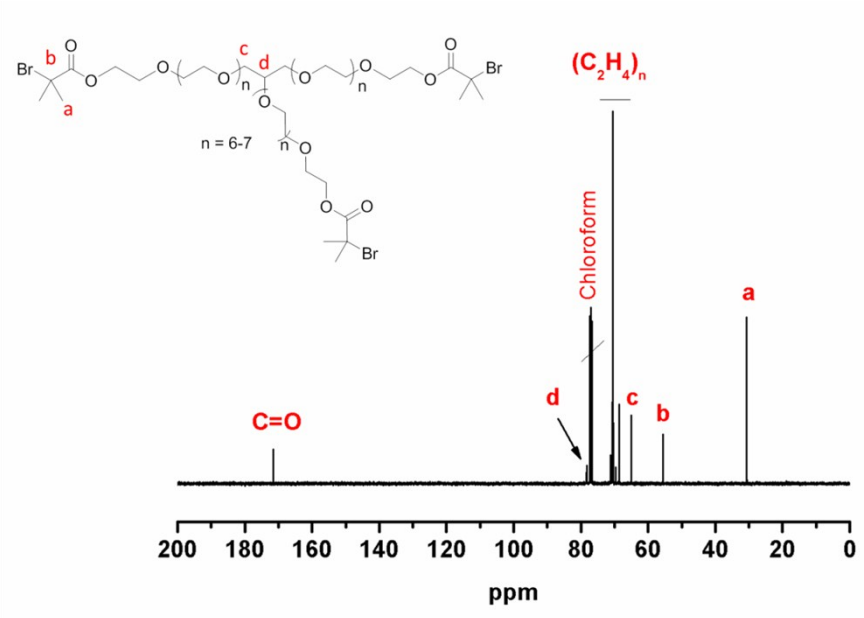
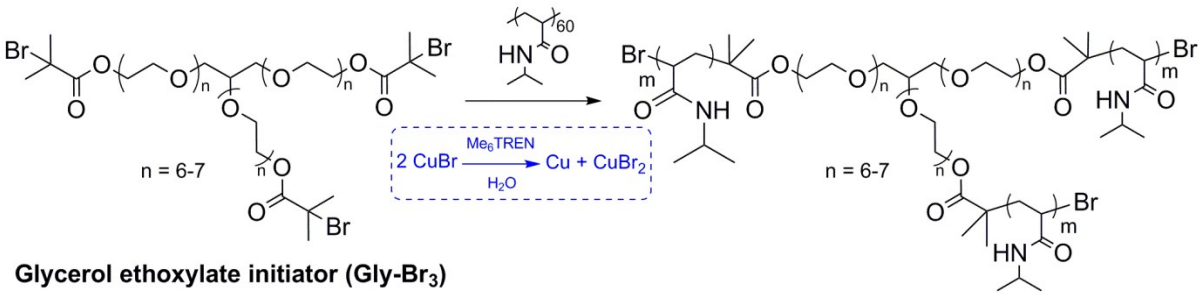


Figure S2: ^{1}H NMR **(A)** and ^{13}C NMR spectrum **(B)** showing successful synthesis of the star initiator **Gly-Br$_3$**.

3.2 Optimisation reactions for aqueous SET-LRP of star PNIPAM (R1-R11):



Glycerol ethoxylate initiator (Gly-Br_3)

To a Schlenk tube fitted with a magnetic stirrer bar, different amounts of CuBr was weighed in and deoxygenated for 20 minutes **(Table S1).** The Schlenk tube was sealed with a rubber septum under a positive Argon pressure and lowered into an ice bath or oil bath set to 25°C. Then, respective amounts of Me_6TREN was added into a sealed vial with 2.5 mL of H_2O and deoxygenated for 15 minutes (Vial 1). Next, Vial 1 was transferred into the Schlenk tube with a degassed syringe and left for disproportionation for 30 minutes at 0°C or 25°C. Similarly in another vial (Vial 2), NIPAM (447 mg) and Gly-Br_3 (125 mg) were dissolved in 2 mL of H_2O under stirring and deoxygenated with Argon for 15 minutes. Vial 2 was then transferred with a degassed syringe into the Schlenk tube to start the polymerization. The transfer of Vial 2 defines t_0.

Table S1: Amounts of CuBr and Me_6TREN used in each reaction for **R01-R11**.

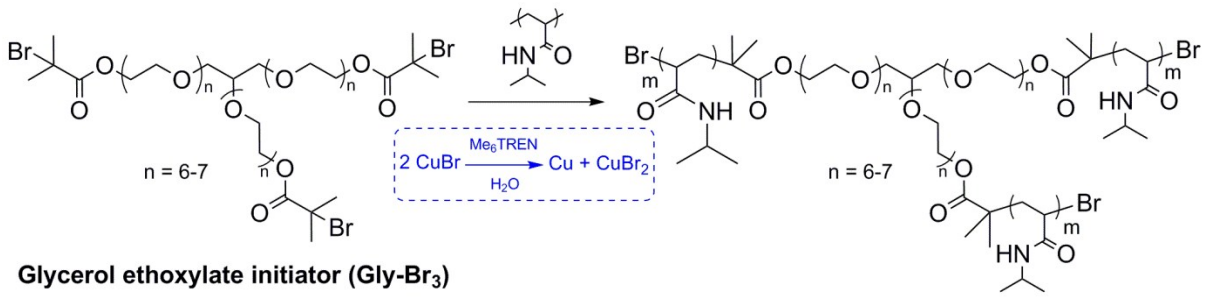
Entry	[M]:[I]:[CuBr]:[Me_6TREN]	CuBr [mg]	Me_6TREN [µL]	Temperature [°C]
R01	60 : 1 : 0.8 : 0.4	10	7	25
R02	60 : 1 : 1.2 : 1.2	11	21	25
R03	60 : 1 : 1.8 : 1.2	17	21	25
R04	60 : 1 : 1.8 : 1.8	17	32	25
R05	60 : 1 : 2.4 : 1.2	22	21	25
R06	60 : 1 : 2.4 : 2.4	22	42	25
R07	60 : 1 : 1.2 : 1.2	11	21	0
R08	60 : 1 : 1.8 : 1.2	17	21	0
R09	60 : 1 : 1.8 : 1.8	17	32	0
R10	60 : 1 : 2.4 : 1.2	22	21	0
R11	60 : 1 : 2.4 : 2.4	30	42	0

Table S2: Summary of the optimization reactions obtained from the polymerization of NIPAM under various reaction conditions.

Entry	[I]:[CuBr]:[Me_6TREN]	$\bar{M}_{n,theo}$ [a] [g·mol^{-1}]	$\bar{M}_{n,SEC}$ [a] [g·mol^{-1}]	PDi [a]	ρ [b] [%]	T [°C]
R01	1:0.8:0.4	3600	6000	1.12	38	25
R02	1:1.2:1.2	8300	11900	1.41	100	25
R03	1:1.8:1.2	8300	12700	1.14	100	25
R04	1:1.8:1.8	8300	15800	1.48	100	25
R05	1:2.4:1.2	6400	8800	1.30	100	25
R06	1:2.4:2.4	8300	15900	1.29	79	25
R07	1:1.2:1.2	8300	12300	1.13	100	0
R08	1:1.8:1.2	8300	10500	1.10	100	0
R09	1:1.8:1.8	8300	17100	1.24	100	0
R10	1:2.4:1.2	3600	5400	1.07	37	0
R11	1:2.4:2.4	8300	15900	1.30	100	0

[a]DMF eluent, PMMA standards, [b]conversion (ρ) measured by ^{1}H-NMR.

3.3 Aqueous SET-LRP of star PNIPAM with increasing DP_n (P1-P7):



Glycerol ethoxylate initiator (Gly-Br_3)

In a typical reaction, CuBr (15 mg) was weighed into a Schlenk tube and fitted with a stirrer bar and deoxygenated with Argon for 20 minutes. The Schlenk tube was sealed with a rubber septum under a positive pressure of Argon and lowered into an ice bath. In the meanwhile, Me_6TREN (21 µL) was added to a vial with 2.5 mL of H_2O and sealed and degassed for 15 minutes (Vial 1) in an ice bath. Vial 1 was then transferred with a degassed syringe into the Schlenk tube and allowed to disproportionate for 30 minutes. In another vial (Vial 2), NIPAM (DP_n = 60-240) and Gly-Br_3 (125 mg, 1900 $gmol^{-1}$) were dissolved in H_2O under stirring and deoxygenated with Argon for 20 minutes at 0°C **(Table S2)**. Vial 2 was then transferred with a degassed syringe into the Schlenk tube to start the polymerization. The transfer of Vial 2 defines t_0.

Table S3: Amounts of NIPAM used to obtain polymers **P1** to **P7** with increasing DP_n

Entry	DP_n	NIPAM [g]	H_2O[a] [mL]
P1	60	0.447	2.0
P2	90	0.670	3.0
P3	120	0.893	4.0
P4	150	1.117	7.0
P5	180	1.340	7.5
P6	210	1.563	9.0
P7	240	1.787	9.0

[a]Indicates the amount of water used to dissolve NIPAM and Gly-Br_3 only prior to addition into the Schlenk tube.

3.4 Aqueous SET-LRP of the sequence controlled star polymers (P8-P11)

The polymerizations were carried out as described for the synthesis of star PNIPAM. CuBr (15 mg) was weighed into a Schlenk tube and carefully fitted with a stirrer bar and deoxygenated with Argon for 20 minutes. The Schlenk tube was slowly sealed with a rubber septum under a positive pressure of Argon and lowered into an ice bath. In the meanwhile, Me_6TREN (21 µL) was added to a vial with 2.5 mL of H_2O and sealed and degassed for 15 minutes (Vial 1) in an ice bath. Vial 1 was then transferred with a degassed syringe into the Schlenk tube and allowed to disproportionate for 30 minutes at 0°C. In another vial (Vial 2), NIPAM (0.447 g, 4mmol) and Gly-Br_3 (125 mg, 1900 gmol^{-1}) were dissolved in 2 mL of H_2O under stirring and deoxygenated with Argon for 20 minutes at 0°C. Vial 2 was then transferred with a degassed syringe into the Schlenk tube to start the polymerization of the first $PNIPAM_{60}$ block. Once desired conversion was reached, the monomer for the next block was added to the Schlenk tube containing the polymer, as described for Vial 2 above in the following amounts (**Table S4**) to obtain **P8-P10** and the pentablock copolymer **P11**:

Table S4: Amounts of monomer and H_2O used for the chain extensions to obtain polymers **P8-P11.**

Entry	Monomer	DP_n	Amount	H_2O[a] [mL]
P8	NIPAM	120	894 mg	4.0
P9	DMA	120	814 µL	4.0
P10	HEAm	120	820 µL	4.0
P11.2	DMA	60	407 µL	2.0
P11.3	NIPAM	60	447 mg	2.0
P11.4	DMA	60	407 µL	2.0
P11.5	HEAm	60	410 µL	2.0

[a]Indicates the amount of water used to dissolve the monomer prior to addition into the Schlenk tube.

Before every chain extension, the monomer consumption for the previous block was monitored by sampling every 3 or 5 minutes to determine full conversion. Once this was done, a new reaction was started from beginning, where this time the successive block was investigated, until the desired polymer was obtained. Chain extensions were carried out at a conversion ≥95% (by ^{1}H NMR).

Table S5: Overview of the obtained results for the synthesized diblock star copolymers **P8, P9** and **P10**.

Entry	Structure	$\bar{M}_{n,theo}$ [g·mol^{-1}]	$\bar{M}_{n,GPC}$[a] [g·mol^{-1}]	PDi[a]	ρ[b] [%]
P0	**Gly-Br_3**	1450	1900	1.04	-
P8	**$PNIPAM_{60}$-*b*- $PNIPAM_{120}$**	21800	24200	1.11	100
P9	**$PNIPAM_{60}$-*b*-$PDMA_{120}$**	20100	24900	1.14	100
P10	**$PNIPAM_{60}$-*b*-$PHEAm_{120}$**	22100	23700	1.14	99

[a]DMF eluent, PMMA standards, [b]conversion ***(ρ)*** measured by ^{1}H-NMR.

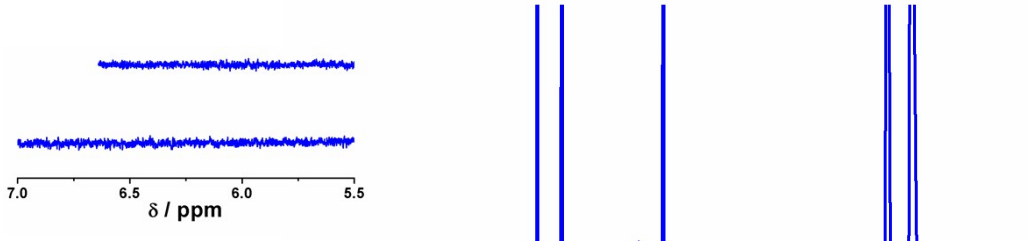


Figure S3: ^{1}H NMR spectra of **P8**; before and after chain extension displaying full conversion for each block.

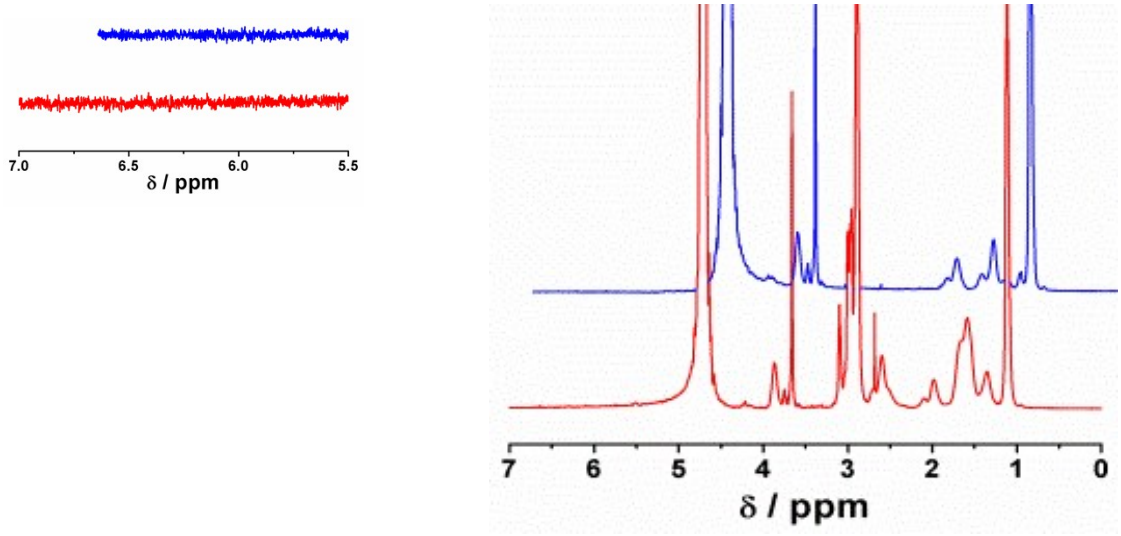


Figure S4: ^{1}H NMR spectra of **P9**; before and after chain extension displaying full conversion for each block.

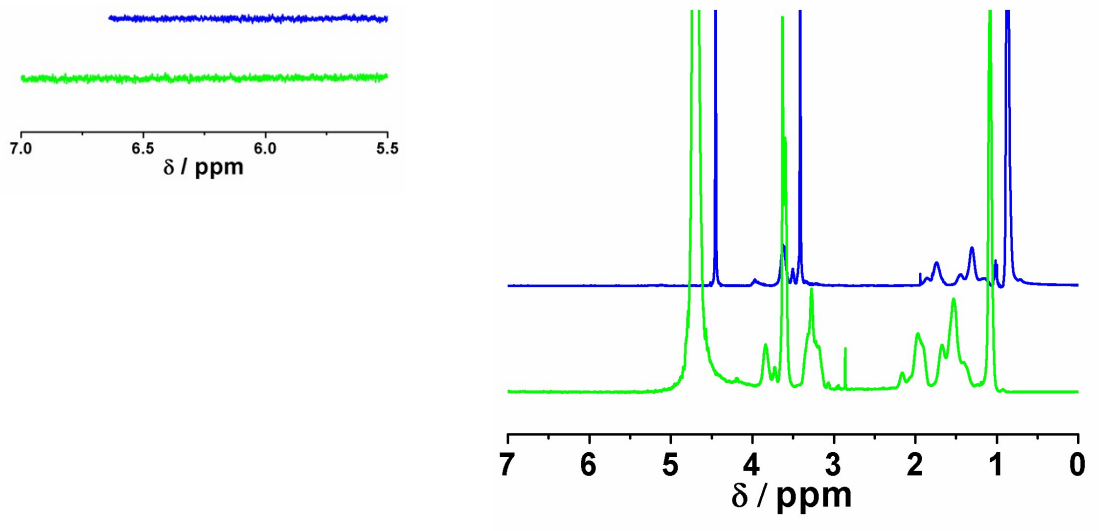


Figure S5: ^{1}H NMR spectra of **P10**; before and after chain extension displaying full conversion for each block.

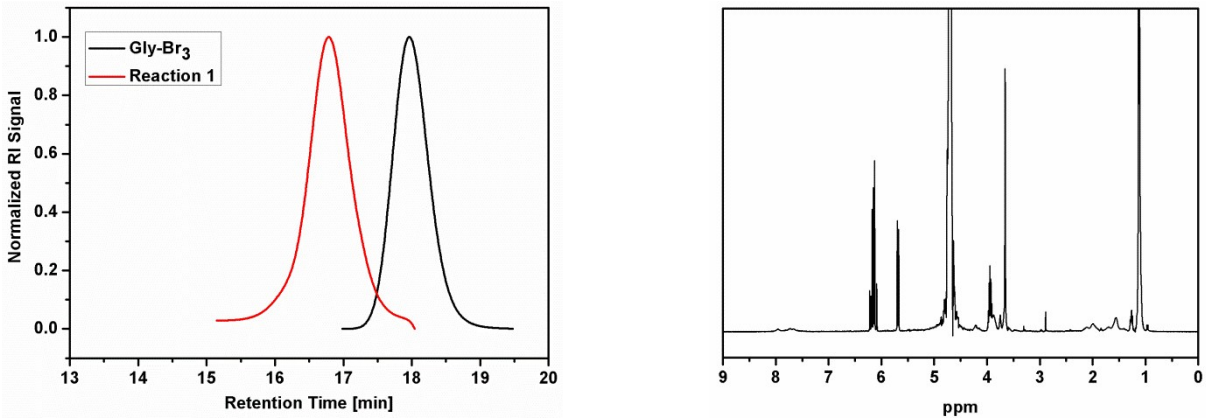


Figure S6: GPC trace (left) and ^{1}H NMR spectrum (right) obtained from reaction 1 (**R1**) showing an $M_{n,GPC}$ = 6000, PDi = 1.12 and 38% conversion.

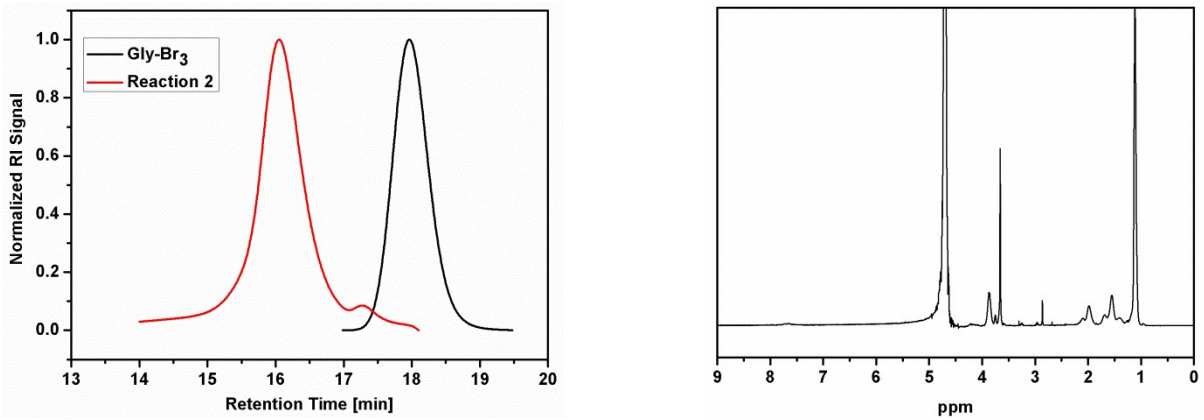


Figure S7: GPC trace (left) and ^{1}H NMR spectrum (right) obtained from reaction 2 (**R2**) showing an $M_{n,GPC}$ = 11900, PDi = 1.41 and 100% conversion.

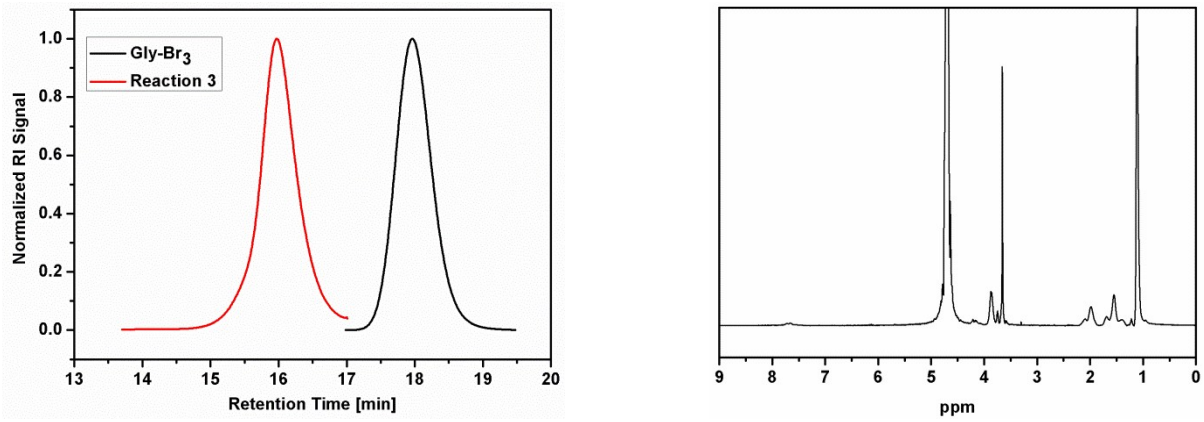


Figure S8: GPC trace (left) and ^{1}H NMR spectrum (right) obtained from reaction 3 (**R3**) showing an $M_{n,GPC}$ = 12700, PDi = 1.14 and 100% conversion.

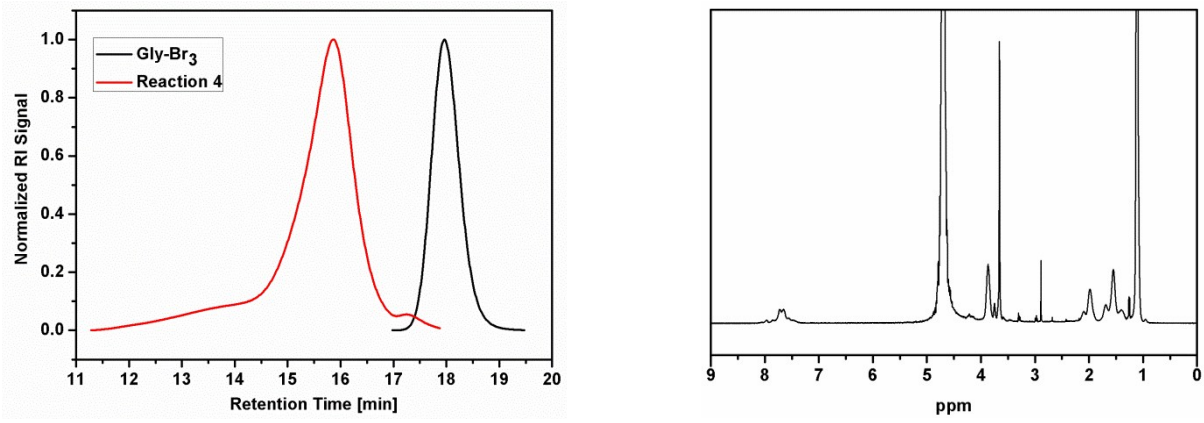


Figure S9: GPC trace (left) and ^{1}H NMR spectrum (right) obtained from reaction 4 (**R4**) showing an $M_{n,GPC}$ = 15800, PDi = 1.48 and 100% conversion.

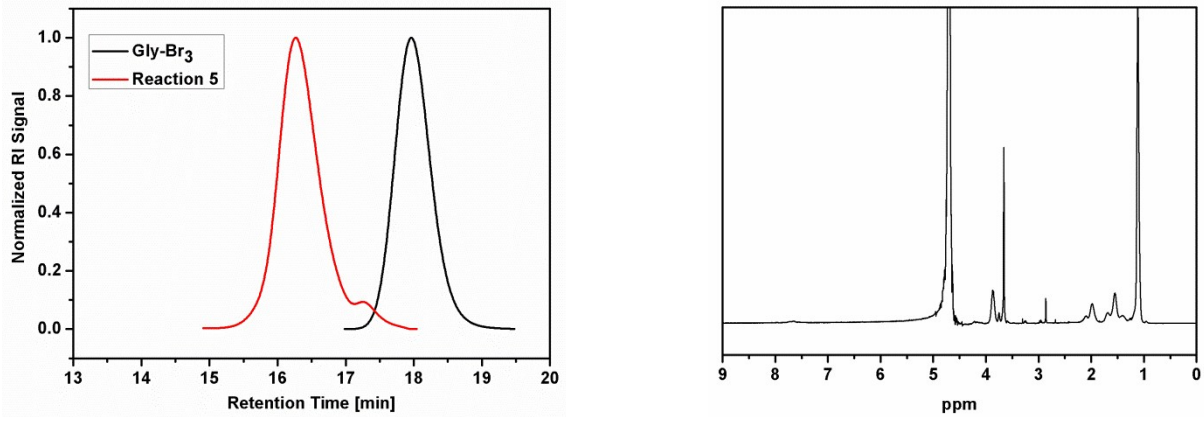


Figure S10: GPC trace (left) and ^{1}H NMR spectrum (right) obtained from reaction 5 (**R5**) showing an $M_{n,GPC}$ = 8800, PDi = 1.30 and 100% conversion.

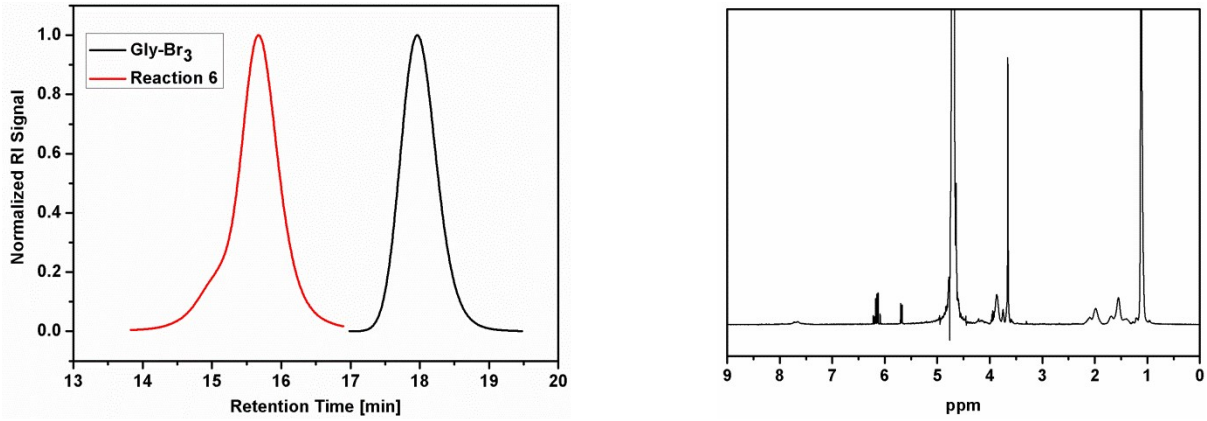


Figure S11: GPC trace (left) and ^{1}H NMR spectrum (right) obtained from reaction 6 (**R6**) showing an $M_{n,GPC}$ = 15900, PDi = 1.29 and 79% conversion.

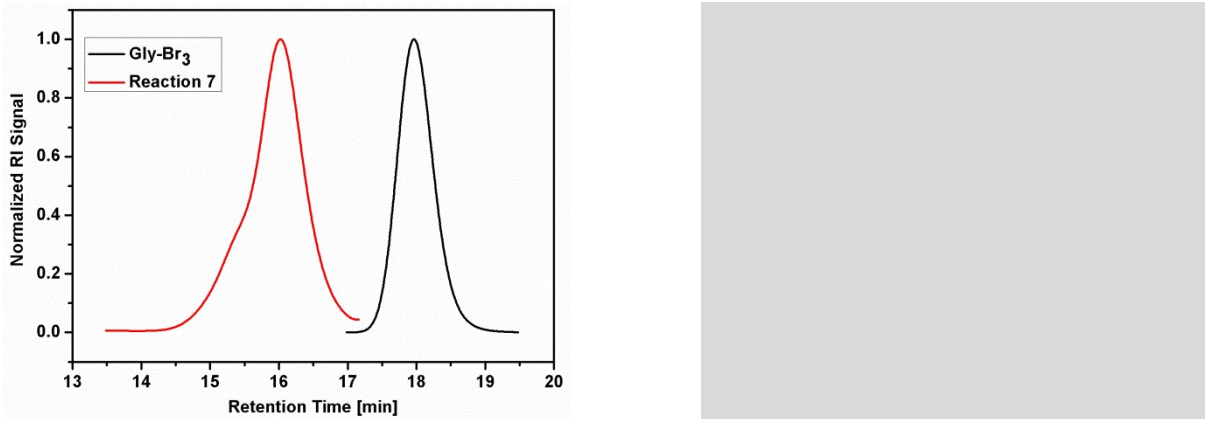


Figure S12: GPC trace (left) and ^{1}H NMR spectrum (right) obtained from reaction 7 (**R7**) showing an $M_{n,GPC}$ = 12300, PDi = 1.13 and 100% conversion.

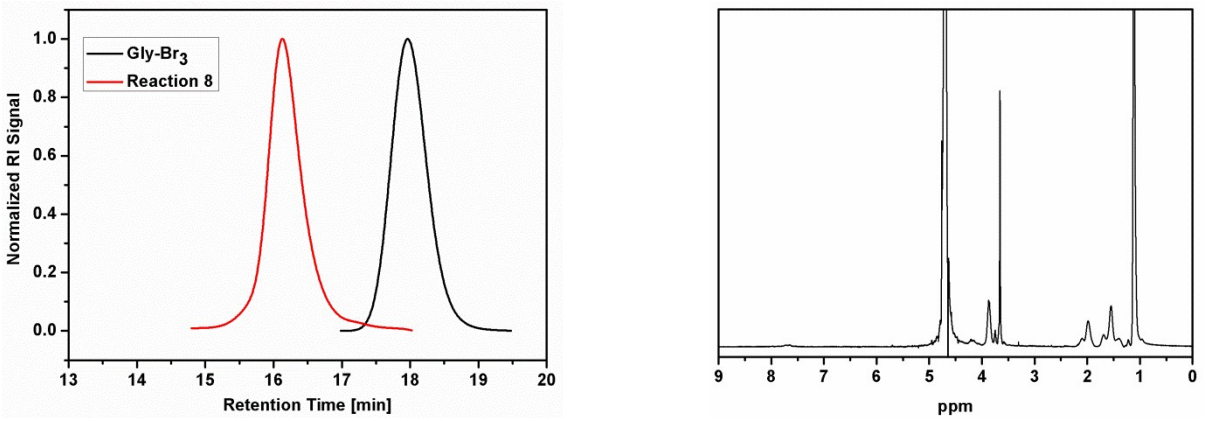


Figure S13: GPC trace (left) and ^{1}H NMR spectrum (right) obtained from reaction 8 (**R8**) showing an $M_{n,GPC}$ = 10500, PDi = 1.10 and 100% conversion.

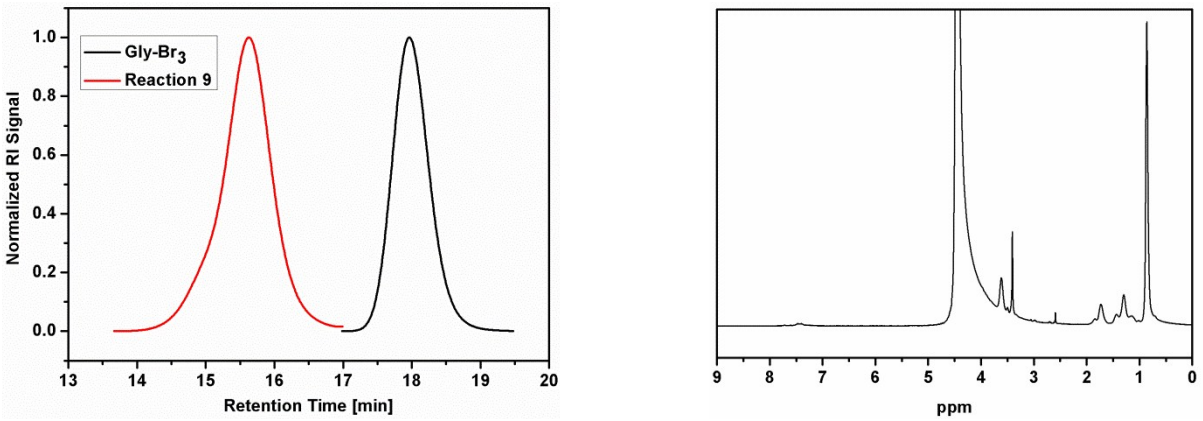


Figure S14: GPC trace (left) and ^{1}H NMR spectrum (right) obtained from reaction 9 (**R9**) showing an $M_{n,GPC}$ = 17100, PDi = 1.24 and 100% conversion.

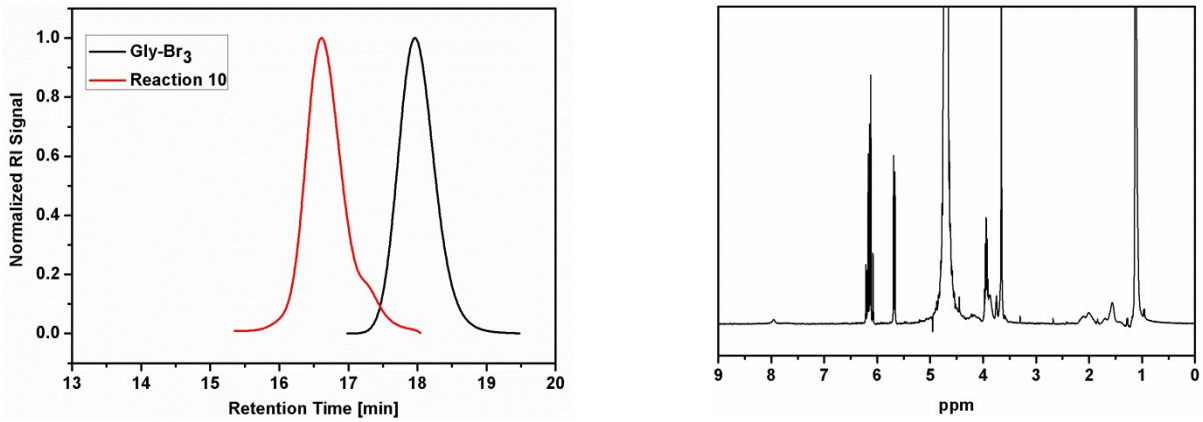


Figure S15: GPC trace (left) and ^{1}H NMR spectrum (right) obtained from reaction 10 (**R10**) showing an $M_{n,GPC}$ = 5400, PDi = 1.07 and 37% conversion.

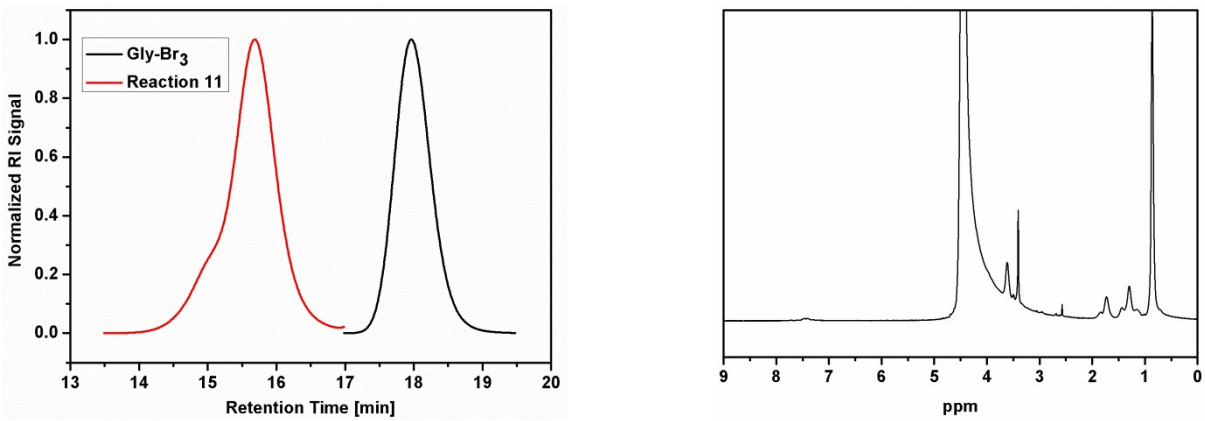


Figure S16: GPC trace (left) and ^{1}H NMR spectrum (right) obtained from reaction 11 (**R11**) showing an $M_{n,GPC}$ = 15900, PDi = 1.30 and 100% conversion.

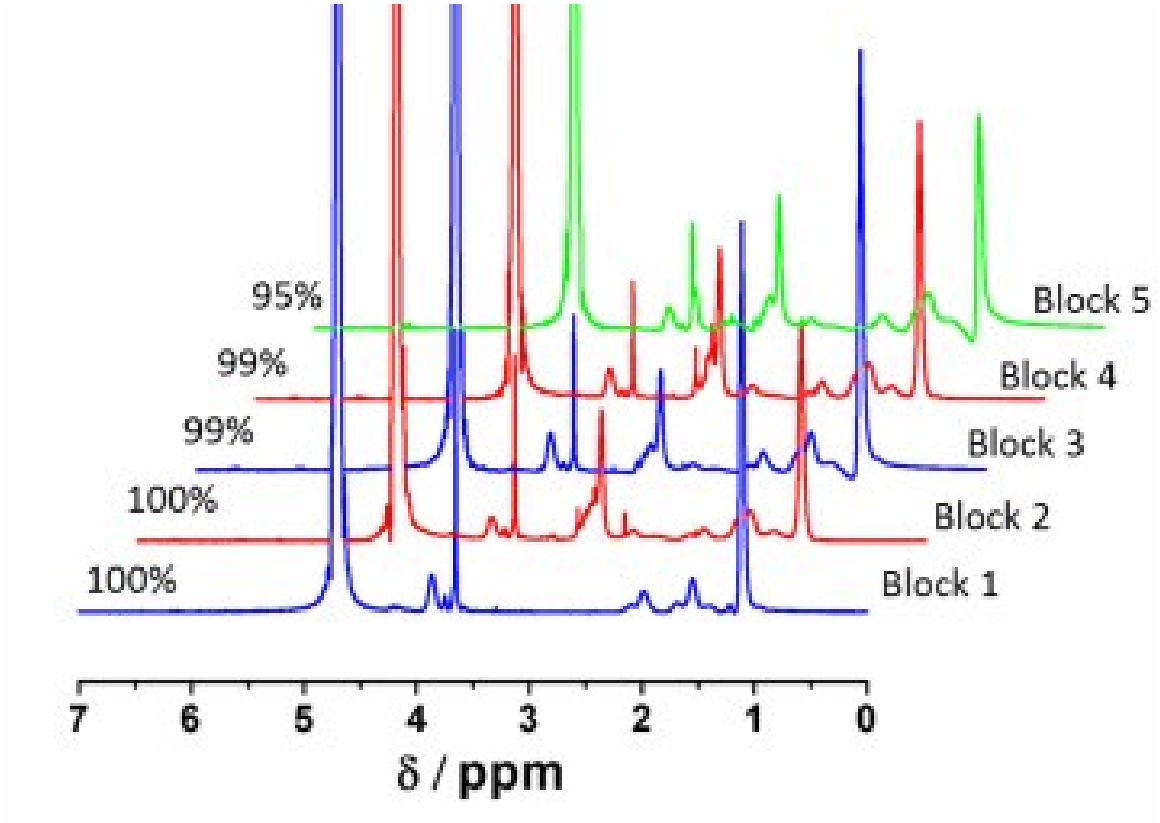


Figure S17: 1H NMR traces of penta block copolymer (P11)

4. References

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(3) R.N. Keller and H.D. Wycoff, *Inorganic Synthesis*, **1946**, *2*, 1-4.