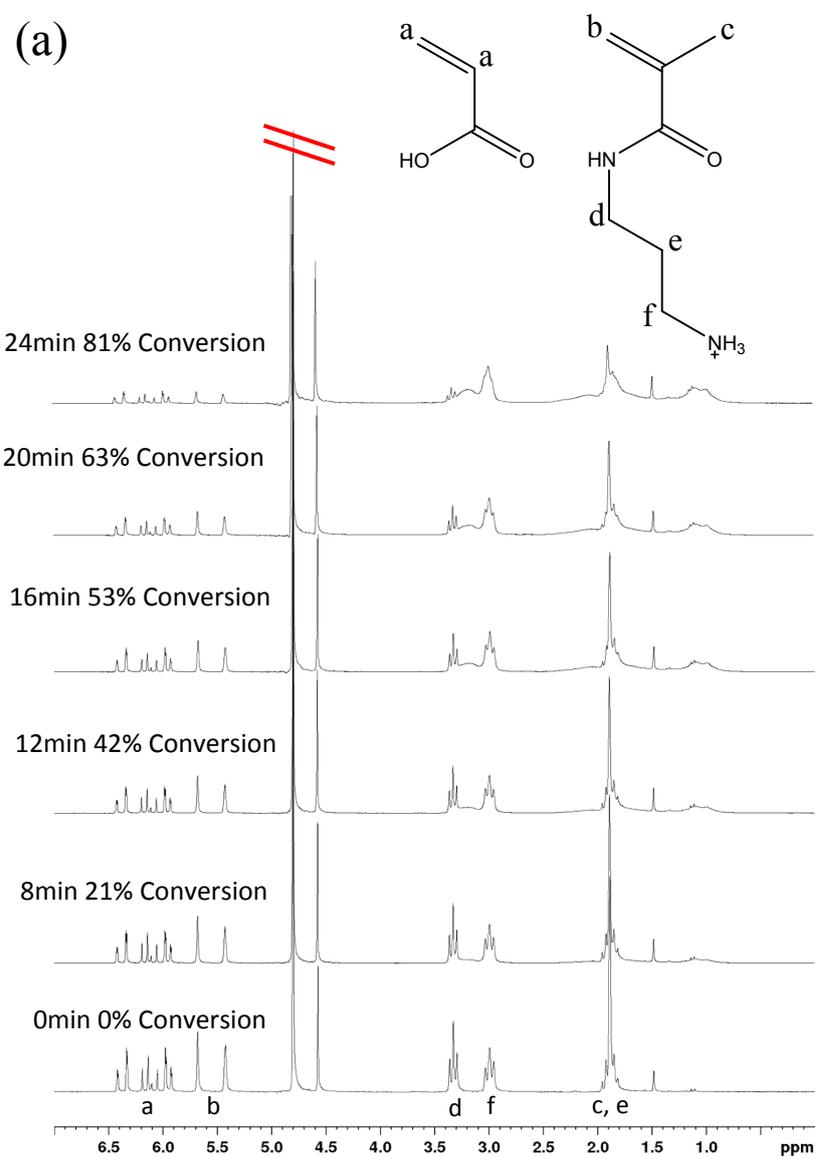


Supporting Information

Preparation and Study of Multi-Responsive Polyampholyte Copolymers of *N*-(3-Aminopropyl)methacrylamide Hydrochloride and Acrylic Acid

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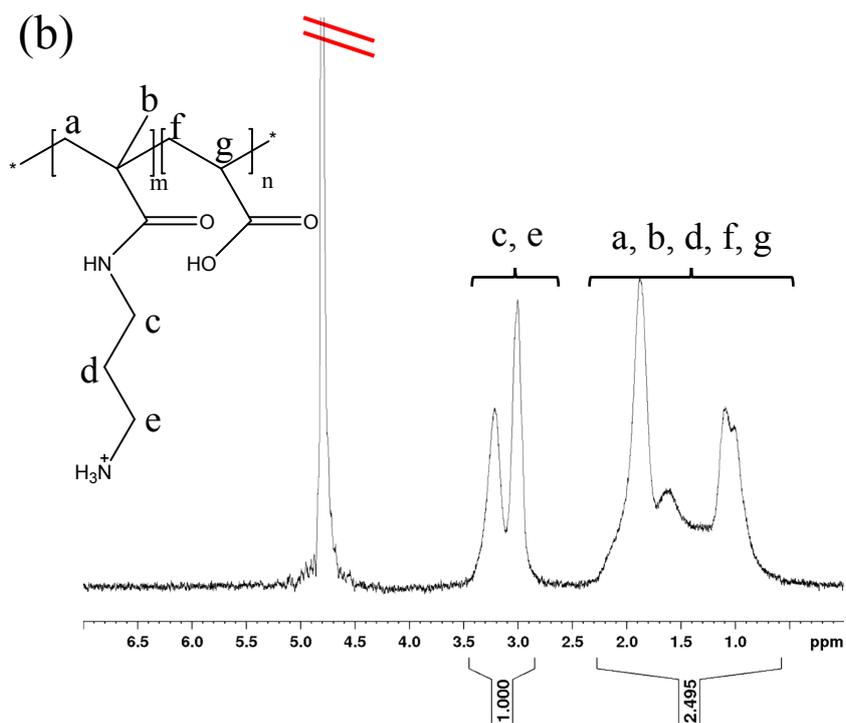


Figure S1. (a) ^1H NMR (200 MHz) spectra taken during copolymerization of a 50:50 APM/AA monomer mixture in D_2O as a function of reaction time at 55°C . The peak at ~ 4.6 ppm is from ethylene carbonate, the internal standard. (b) ^1H NMR (600 MHz) spectrum of PMA_{52} copolymer in D_2O .

Calculation of reactivity ratios

The reactivity ratios were calculated by fitting the copolymer equation to values of f_1 and F_1 , the APM mol fraction in the monomer mixture and the polymer, respectively, as determined by ^1H NMR from eight separate polymerizations. The change in monomer composition with conversion for all of the polymerizations is shown in Figure 1 (main text). These gave 42 individual polymerization steps, of which 5 were excluded in the final fitting. Two steps involved a very small conversion leading to a large uncertainty in F_1 (copolymer composition) while in two others near the end of polymerization, the monomer composition (f_1) changed significantly (>10 mol%) during the step. These changes simply mean that the neighbouring steps or increments become slightly larger, so the relevant conversion data are not lost.

In addition, two of the remaining 39 data points were excluded from the final fitting as they were clear outliers (see Figure 2, main text). The copolymer equation (shown below) was fitted to the 37 data points shown in Table S1 with the method of non-linear Generalized Reduced Gradient algorithm in the Solver subroutine of Microsoft

Excel 2007 resulting in r_1 (APM) and r_2 (AA) values of 0.68 and 0.48, respectively. The F_1 values calculated using these r_1 and r_2 values are also shown in Table S1.

Copolymerization equation:

$$F_1 = \frac{r_1 f_1^2 + f_1 f_2}{r_1 f_1^2 + f_1 f_2 + r_2 f_2^2}$$

Table S1: f_1 and F_1 values for determination of reactivity ratios.^a

f_1	F_1 (exp)	F_1 (calc)	f_1	F_1 (exp)	F_1 (calc)
0.90	0.83	0.87	0.42	0.50	0.47
0.92	0.89	0.89	0.41	0.48	0.46
0.93	0.93	0.91	0.39	0.47	0.45
0.94	0.89	0.91	0.36	0.42	0.43
0.95	0.94	0.93	0.29	0.33	0.37
0.75	0.68	0.72	0.27	0.36	0.36
0.76	0.73	0.73	0.25	0.36	0.33
0.80	0.78	0.76	0.20	0.30	0.29
0.80	0.79	0.77	0.20	0.25	0.28
0.81	0.80	0.77	0.18	0.25	0.26
0.63	0.61	0.62	0.15	0.24	0.23
0.63	0.63	0.62	0.11	0.20	0.18
0.63	0.66	0.62	0.08	0.11	0.14
0.62	0.54	0.62	0.094	0.13	0.16
0.52	0.56	0.55	0.087	0.14	0.15
0.53	0.55	0.55	0.060	0.10	0.11
0.51	0.58	0.53	0.040	0.10	0.08
0.49	0.52	0.53	0.01	0.02	0.03
0.49	0.54	0.52			

a. f_1 is the APM fraction in the monomer mixture at the beginning of a heating segment while F_1 is the APM content of the copolymer formed in that segment as determined by the amount of the two monomers consumed.

Table S2. Predicted drift in composition during preparation of PMA_x, starting from 8.8:91.2 (PMA₁₂), 29.4:70.6 (PMA₃₅) and 51:49 (PMA₅₂) APM/AA monomer mixtures, estimated using a series of 10% Conversion Steps. Predicted Comonomer Sequence Distributions calculated by the method of Igarashi.¹

Conversion (%)	% APM in polymer										Blockiness (%)		Alternation (%)
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	APM	AA	
PMA ₁₂	14.8	13.8	12.7	11.5	10.2	8.7	7.1	5.3	3.3	1.0	0.3	82.3	17.1
PMA ₃₅	37.0	36.3	35.4	34.3	33.0	31.4	29.3	26.2	21.2	10.2	4.5	45.6	49.9
PMA ₅₂	53.7	53.5	53.2	52.9	52.5	52.0	51.3	50.3	48.5	42.3	19.2	17.2	63.6

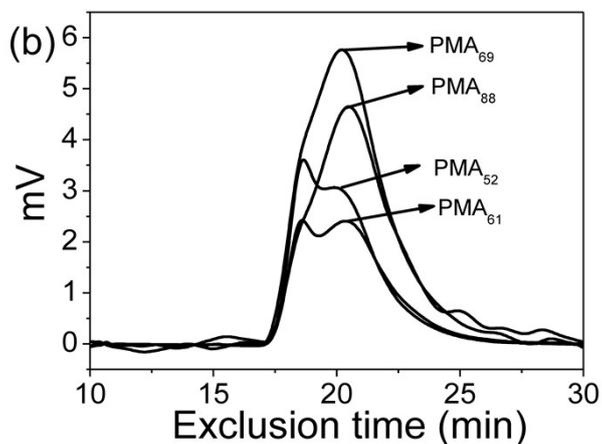
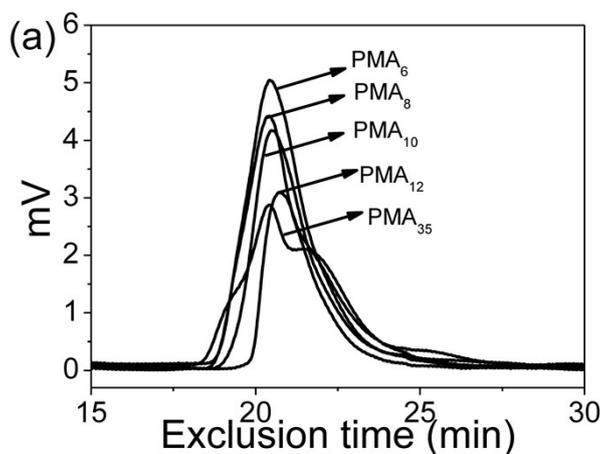


Figure S2. GPC curves of PMA_x, (a) pH 9, (b) pH 4.75.

Table S3. Composition of PMA₃₇, PMA₄₃ and PMA₄₇.

	APM Feed (mol%)	Conversion (%)	mol% APM in Copolymer	
			Predicted from reactivity ratios	¹ H-NMR (600 MHz) of copolymer
PMA ₃₇	36.5	76	40	37
PMA ₄₃	39.3	81	42	43
PMA ₄₇	44.3	62	48	47

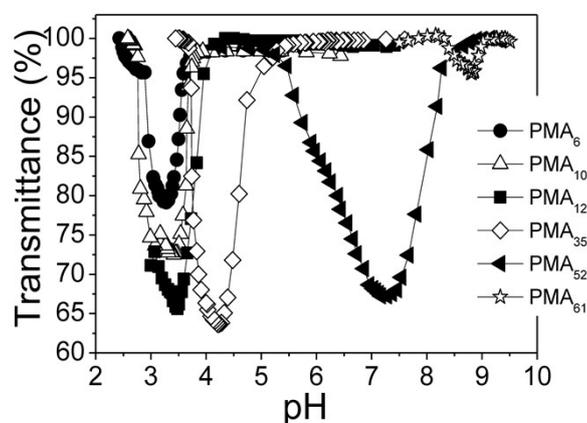


Figure S3. Turbidity titrations of PMA_x (x = 6-61). Conditions: 0.1 mg/mL polymer in water, no added salt, titrant: 0.01-1 M HCl. Data collection for PMA₁₂ was stopped at pH 3 because the phase-separated material deposited on the pH and optical probes.

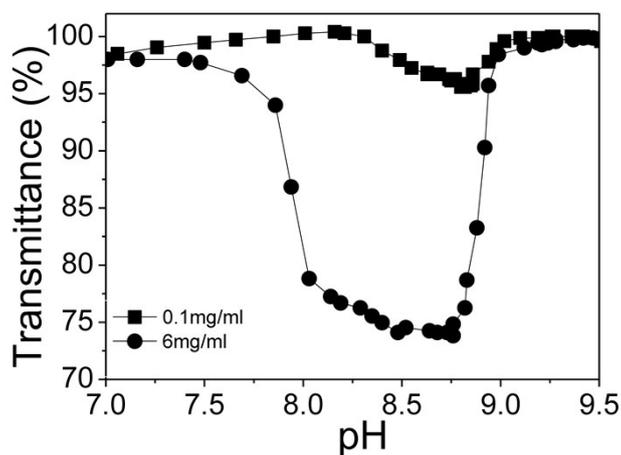


Figure S4. The effect of polymer concentration on the turbidity titration of PMA₆₁ titrated with HCl (pH decreasing). Conditions: no added salt, titrant: 0.01-1 M NaOH or HCl.

Calculation of the fraction of charged/non-charged monomer residues on PMA_x at different pH

The calculation of the fraction of different species (NH₂, NH₃⁺, COOH, COO⁻, NH₃⁺/COO⁻ ion pair) in the polyampholytes at different pH is based on the Henderson–Hasselbalch equation:

$$pH = pK_a + \log_{10} \left(\frac{[A^-]}{[HA]} \right)$$

The pKa of monomeric AA is 4.26 and that of APM is close to 9.1, and the ratio of APM and AA in PMA₁₂ is 12.7:87.3; in PMA₃₅ is 35:65 and in PMA₅₂ is 52.3:47.7. For simplicity, it is assumed that the pKa values did not change upon polymerization and do not change with pH, and that the cationic and anionic groups will form ion pairs with 100% efficiency. For example, PMA₁₂ is calculated to have 12.7% NH₃⁺, 86.8% COOH and 1.22% COO⁻ at pH 2.5. If all of the COO⁻ groups form ion pairs with NH₃⁺ ones, it leaves an excess of 11.5% NH₃⁺.

Table S4. The calculation of the net charge and the fraction of monomers existing as different species (NH₂, NH₃⁺, COOH, COO⁻, NH₃⁺/COO⁻ ion pair) on the polyampholyte chain as a function of pH, (a) PMA₅₂ (actual composition 52.3:47.7); (b) PMA₃₅ (actual composition 35:65), and (c) PMA₁₂ (actual composition 12.7:87.3).

(a).

pH	% -NH ₂	% -NH ₃ ⁺	% -COOH	% -COO ⁻	Ion Pair	Net charge
3.00	0.00	50.4	47.0	2.58	5.17	47.8
3.50	0.00	50.4	42.3	7.34	14.7	43.1
4.00	0.00	50.4	32.0	17.6	35.2	32.8
4.50	0.00	50.4	18.1	31.5	63.0	18.9
5.00	0.00	50.4	7.64	42.0	83.9	8.43
5.50	0.01	50.4	2.70	46.9	93.8	3.49
6.00	0.04	50.4	0.89	48.7	97.4	1.65
6.50	0.13	50.3	0.28	49.3	98.6	0.96
7.00	0.40	50.0	0.09	49.5	99.0	0.49
7.50	1.23	49.2	0.03	49.6	98.3	-0.41
8.00	3.71	46.7	0.01	49.6	93.4	-2.90
8.50	10.1	40.3	0.00	49.6	80.6	-9.32
9.00	22.3	28.1	0.00	49.6	56.2	-21.5
9.50	36.1	14.4	0.00	49.6	28.7	-35.6
10.00	44.8	5.6	0.00	49.6	11.3	-44.0
10.50	48.5	1.93	0.00	49.6	3.86	-47.7
11.00	49.8	0.63	0.00	49.6	1.25	-49.0

(b).

pH	% -NH ₂	% -NH ₃ ⁺	%- COOH	% -COO ⁻	Ion Pair	Net charge
3.00	0.00	35.0	61.6	3.39	6.77	31.6
3.25	0.00	35.0	59.2	5.79	11.6	29.2
3.50	0.00	35.0	55.4	9.62	19.3	25.4
3.75	0.00	35.0	49.7	15.3	30.7	19.7
4.00	0.00	35.0	42.0	23.1	46.1	12.0
4.25	0.00	35.0	32.9	32.1	64.3	2.87
4.50	0.00	35.0	23.7	41.3	70.0	-6.26
4.75	0.00	35.0	15.9	49.1	70.0	-14.1
5.00	0.00	35.0	10.0	55.0	70.0	-20.0
5.25	0.00	35.0	6.03	59.0	70.0	-24.0
5.50	0.01	35.0	3.54	61.5	70.0	-26.5
5.75	0.02	35.0	2.04	63.0	70.0	-28.0
6.00	0.03	35.0	1.16	63.8	69.9	-28.9

(c).

pH	% -NH ₂	% -NH ₃ ⁺	%- COOH	% -COO ⁻	Ion Pair	Net charge
2.50	0.00	12.7	85.8	1.49	2.98	11.2
2.75	0.00	12.7	84.7	2.62	5.23	10.1
3.00	0.00	12.7	82.8	4.55	9.10	8.15
3.25	0.00	12.7	79.5	7.77	15.5	4.93
3.50	0.00	12.7	74.4	12.9	25.4	-0.22
3.75	0.00	12.7	66.7	20.6	25.4	-7.91
4.00	0.00	12.7	56.3	31.0	25.4	-18.3
4.25	0.00	12.7	44.2	43.2	25.4	-30.5
4.50	0.00	12.7	31.9	55.4	25.4	-42.7
4.75	0.00	12.7	21.3	66.0	25.4	-53.2
5.00	0.00	12.7	13.4	73.9	25.4	-61.2
5.25	0.00	12.7	8.10	79.2	25.4	-66.5
5.50	0.00	12.7	4.75	82.6	25.4	-69.9
5.75	0.01	12.7	2.74	84.6	25.4	-71.9
6.00	0.01	12.7	1.56	85.7	25.4	-73.1

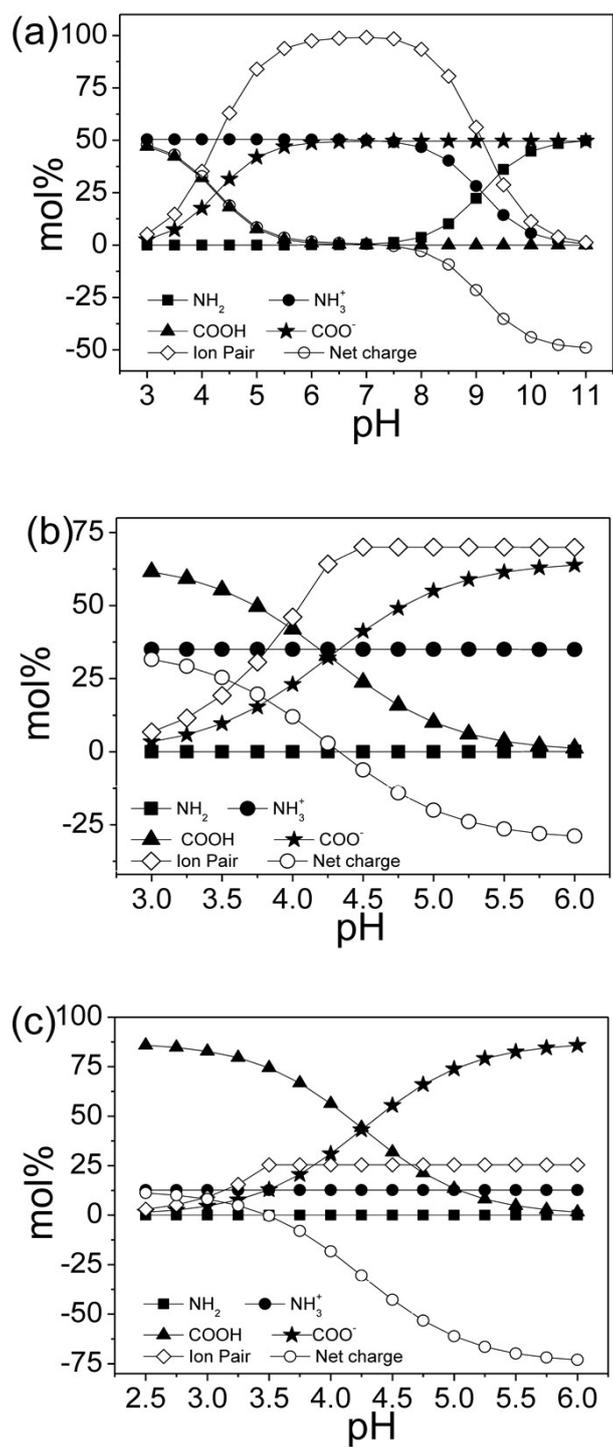
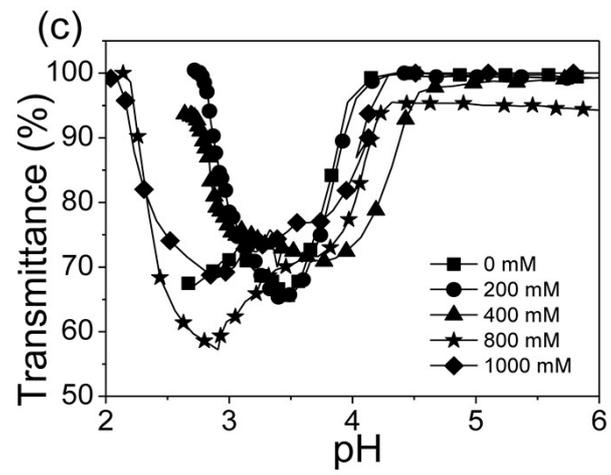
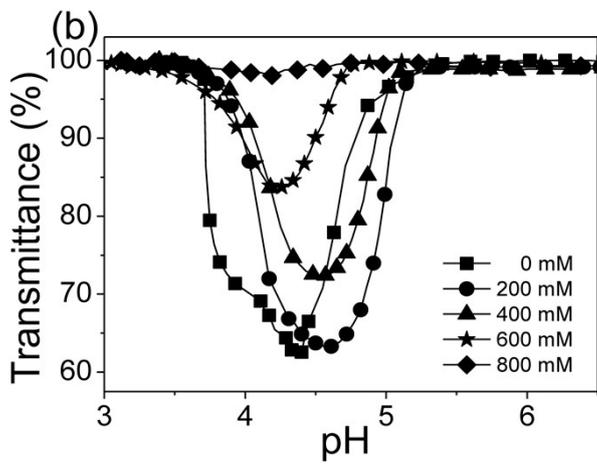
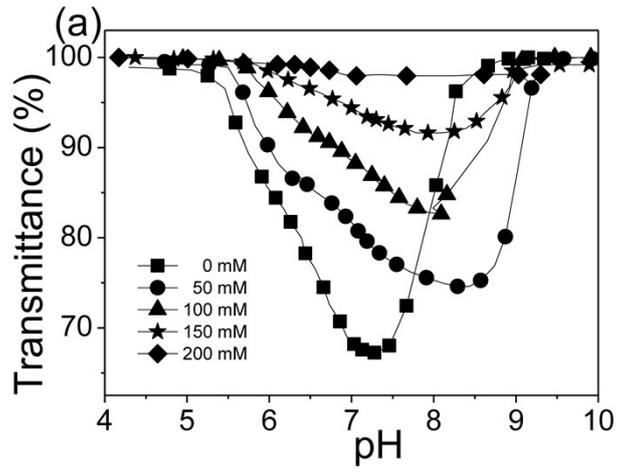


Figure S5. The net charge and the fraction of different species (NH_2 , NH_3^+ , COOH , COO^- , ion pair) on the polyampholyte chain as a function of pH for: (a), PMA₅₂ (actual composition 52.3:47.7); (b) PMA₃₅ (actual composition 35:65), and (c) PMA₁₂ (actual composition 12.7:87.3).



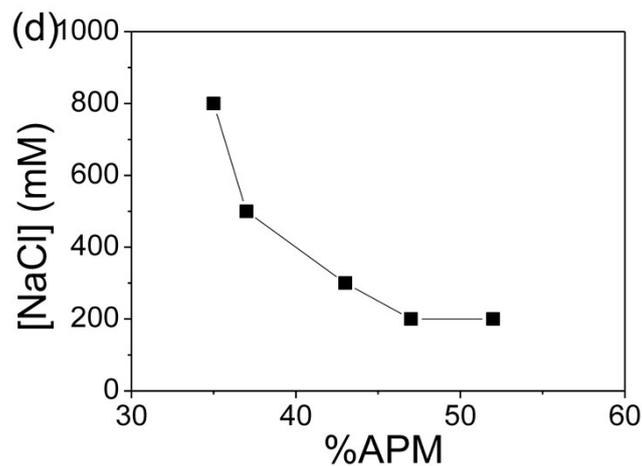


Figure S6. The effect of salt concentration on the turbidity titration curves during titration with HCl (decreasing pH) of (a) PMA₅₂, (b) PMA₃₅ and (c) PMA₁₂, and (d) the ionic strength NaCl needed to solubilize the polyampholytes at pH(I). Conditions: 0.1 mg/mL polymer in water, titrant: 0.01-1 M HCl.

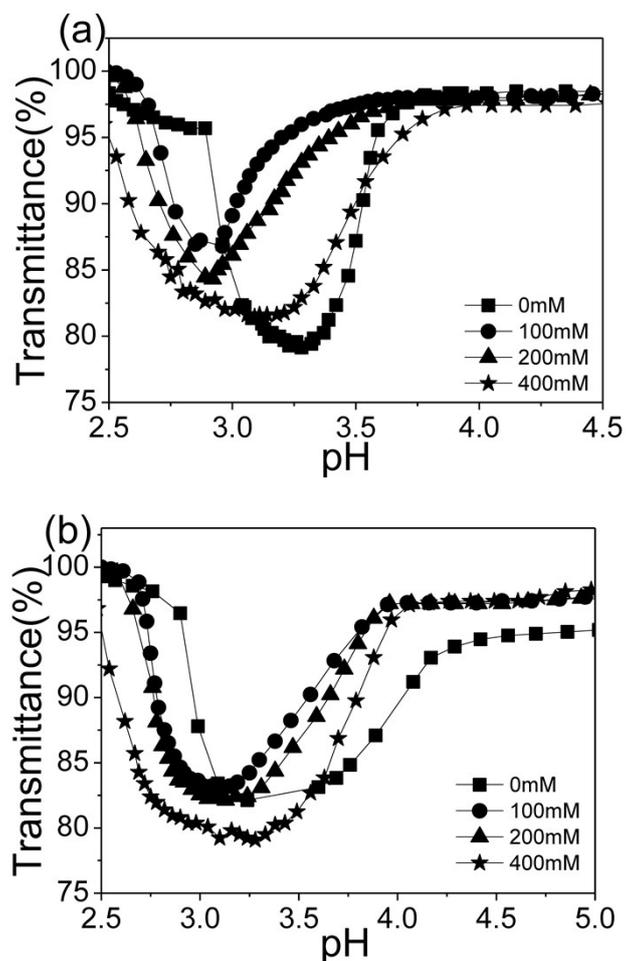


Figure S7. Turbidity titration curves of PMA₆ at different ionic strengths ([NaCl]): (a) decreasing pH, and (b) increasing pH. Conditions: 0.1 mg/mL polymer, titrant: 0.01-1 M HCl and NaOH in (a) and (b), respectively.

Effect of pH and polymer concentration on cloud point of PMA_x

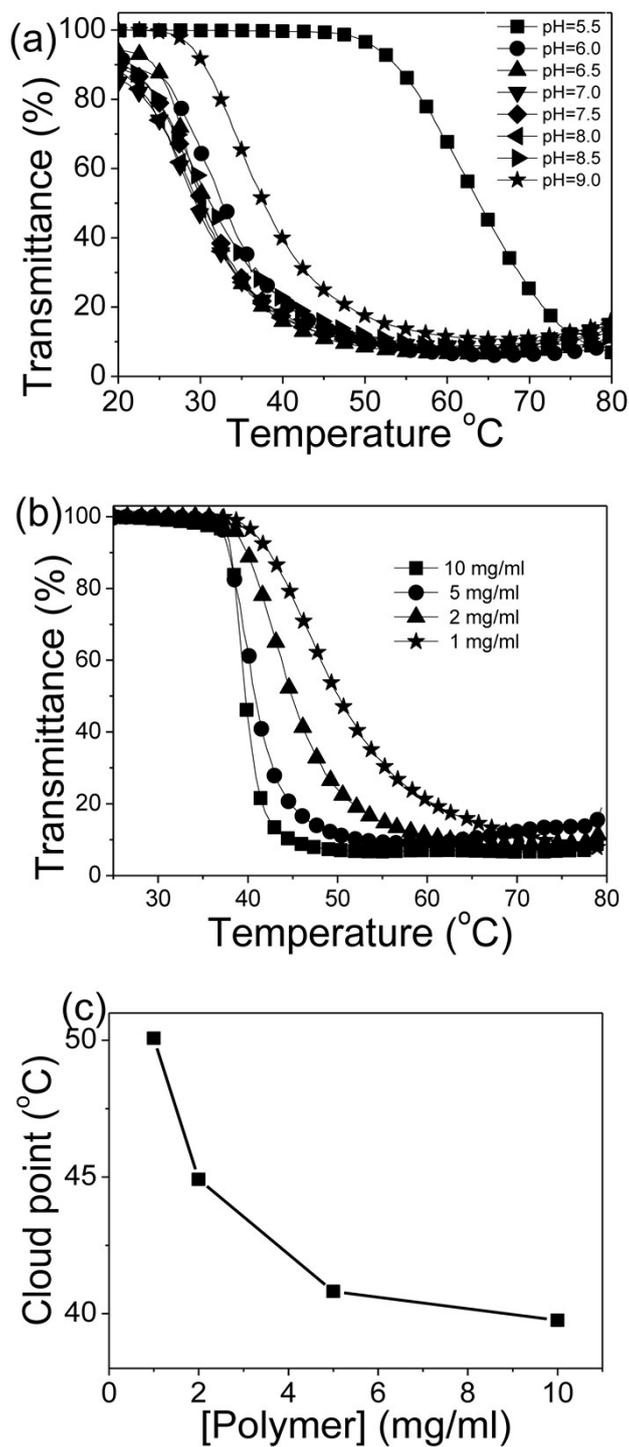


Figure S8. Temperature responsive behaviour of PMA₅₂ at (a) various pH (200 mM NaCl, 0.2 wt% polymer) and (b) various polymer concentrations (225 mM NaCl, pH = pH(I) (pH 7.5)); (c) cloud point vs. polymer concentration (225 mM NaCl, pH = pH(I) (pH 7.5)).

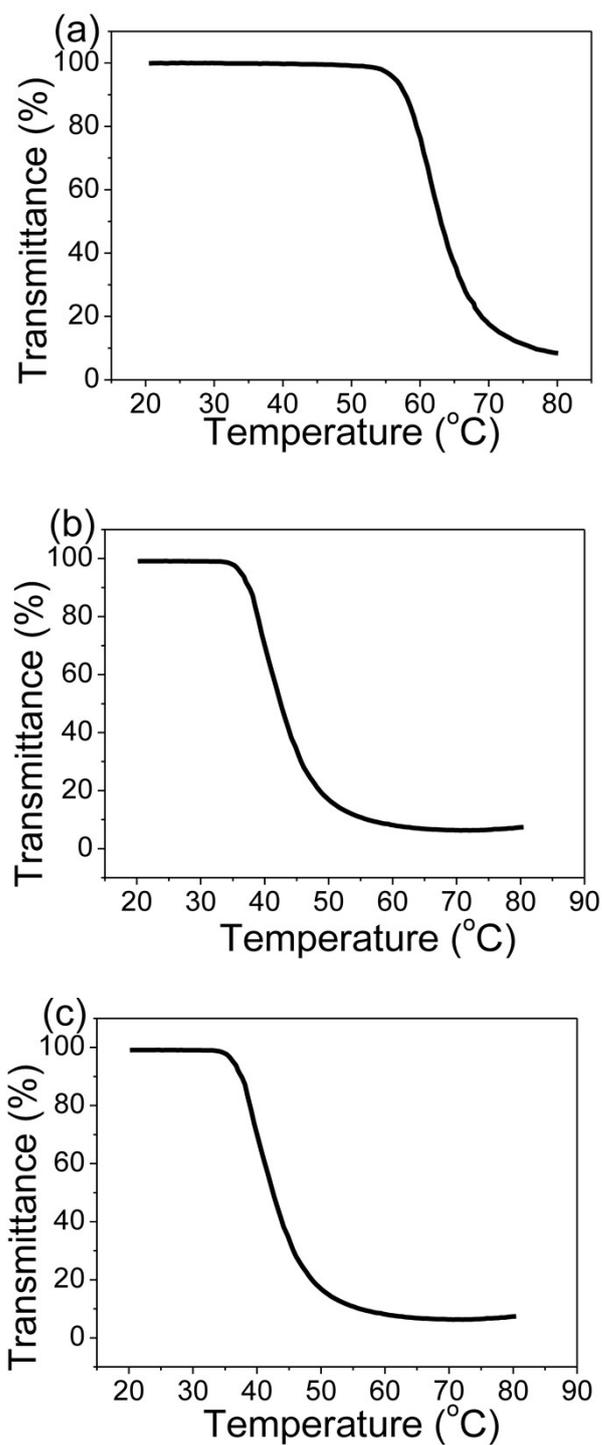


Figure S9. The effect of composition on the temperature-responsive behavior of 0.2 wt% polymer solutions of PMA at pH(I): (a) PMA₃₇ at pH 5.0, 600 mM NaCl, (b) PMA₄₃ at pH 5.2, 350 mM NaCl and (c) PMA₄₇ at pH 5.5, 250 mM NaCl cloud point vs. polymer concentration (225 mM NaCl, pH = pH(I)). Heating rate: 1 °C/min.

References:

1. S. Igarashi, *J. Polym. Sci., Part B: Polym. Lett.*, 1963, **1**, 359-363.