

Electronic Supplementary Information

Synthesis and evaluation of partly-fluorinated polyelectrolytes as components in ^{19}F MRI-detectable nanoparticles

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Contents:

- 1) Experimental details for the synthesis of block copolymers of TFEMA and DMAEMA.
- 2) Experimental details for the synthesis of statistical copolymers of TFEMA and DMAEMA.
- 3) Polymerization results for TFEMA/DMAEMA block and statistical copolymers.
- 4) Reactivity ratio measurements of the DMAEMA/TFEMA monomer pair.
- 5) The exponential decay curves of the spin-spin (T_2) relaxation time measurements.

Experimental details for the synthesis of block copolymers of TFEMA and DMAEMA. The polymerizations were conducted with a [DMAEMA]+[TFEMA]:[CuBr]:[ligand]:[initiator] ratio of 150:1:2.2:1 and monomer/solvent ratio of 1:1 (v:v). The block copolymers were prepared by one-pot sequential polymerization, where PTFEMA block was prepared first and DMAEMA monomer was added at around 80% TFEMA conversion.

Typically: TFEMA (1.6 ml, 11 mmol), *N*-(*n*-pentyl)-2-pyridylmethanimine (119 mg, 0.68 mmol), benzyl 2-bromoisobutyrate (79 mg, 0.31 mmol) and toluene (7.4 ml) were added to a small Schlenk tube. The solution was deoxygenated by three freeze-pump-thaw cycles. Into another small Schlenk tube, CuBr (44 mg, 0.31 mmol) was added, and the tube was evacuated and back-filled with nitrogen several times. The toluene solution was cannulated into this tube. The tube was immersed into a pre-heated, thermostated oil bath at 90 °C. During polymerization, samples were withdrawn at certain time

intervals (with cannula, under N₂ flow) from the polymerization mixture to follow the development of conversion (by ¹H NMR in *d*-chloroform).

At around 80 % TFEMA conversion, deoxygenated DMAEMA (5.8 ml, 35 mmol) was added. The polymerization was stopped when around 70-80% DMAEMA conversion was reached. The polymerization mixture was diluted with toluene and purged with air overnight. The mixture was passed through basic alumina to remove the catalyst. The product was precipitated from cold petroleum ether several times.

The block copolymers were purified by removal of traces of PTFEMA homopolymer by acidification of a solution of the crude polymer in THF with diluted HCl (aq), which led to the exclusive precipitation of the PTFEMA/PDMAEMA block copolymer. The precipitated polymer was recovered by centrifugation, and dissolved in 90:10 THF/triethylamine mixture. The formed salt was removed by filtration and the polymer was precipitated from cold petroleum ether. The purification was followed by SEC (in THF/triethylamine 95:5 v:v, with UV detection at 250 nm). If necessary, the purification was repeated.

Experimental details for the synthesis of statistical copolymers of TFEMA and DMAEMA. The statistical copolymers were polymerized with otherwise similar conditions as the block copolymers, but DMAEMA was added to the mixture at the beginning of the polymerization. Statistical copolymers C-12 and C-24 were polymerized at 90 °C and C-51 was polymerized at 60 °C.

Polymerization results for TFEMA-DMAEMA block and statistical copolymers. *Polymerization kinetics.* The kinetic curves measured by ¹H NMR (in *d*-chloroform) for the block copolymerizations are presented in Figure 1 and for the statistical copolymerizations in Figure 2. The kinetic curves were linear up to high conversions. The curves were calculated by comparing the relative intensities of the monomer peaks (TFEMA 1H at 6.21 ppm, 1H at 5.67 ppm, 2H at 4.50 ppm; DMAEMA 1H at 6.11 ppm, 1H at 5.55 ppm, 2H at 4.24 ppm) to the relative intensities of the polymer side-chain peaks (PTFEMA 2H at 4.33 ppm, PDMAEMA 2H at 4.07 ppm).

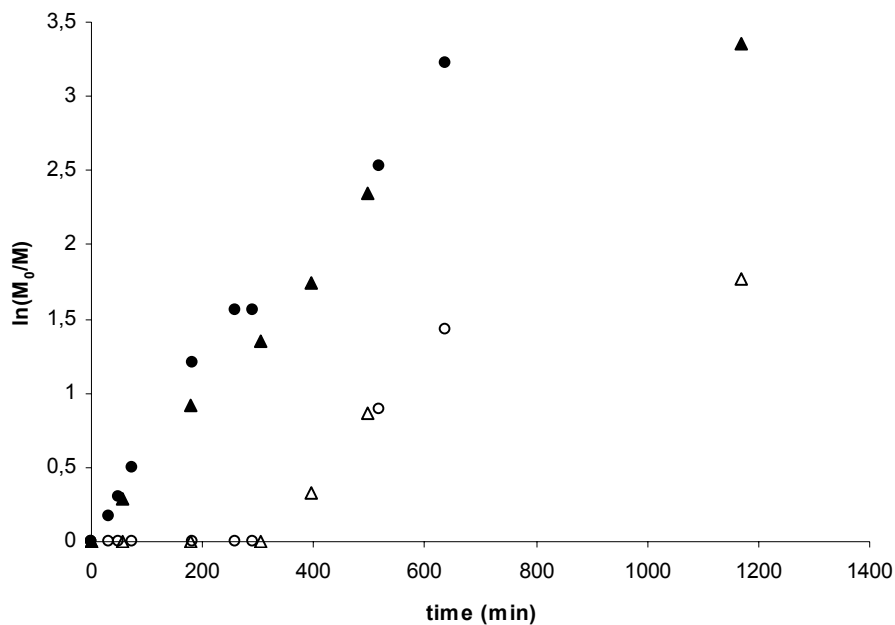


Figure 1. Kinetic curves for the block copolymerizations. ▲ B-20, TFEMA. △ B-20, DMAEMA. ● B-47, TFEMA. ○ B-47, DMAEMA. For both polymerizations, DMAEMA was added 300 min after the reaction was started.

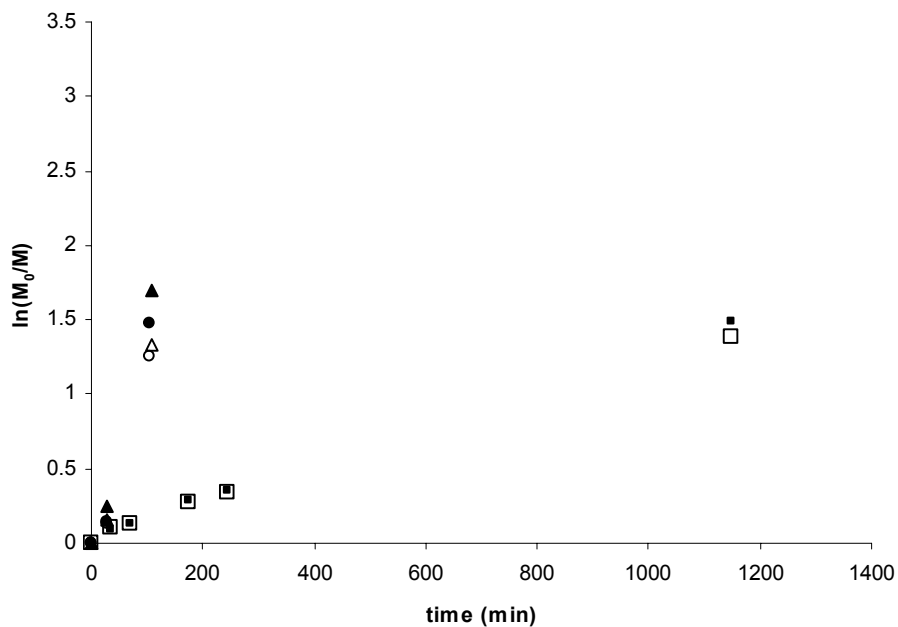


Figure 2. Kinetic curves for the statistical copolymerizations. ▲ C-12, TFEMA. Δ C-12, DMAEMA. ● C-24, TFEMA. ○ C-24, DMAEMA. ■ C-51, TFEMA. □ C-51, DMAEMA. The polymers C-12 and C-24 were polymerized at 90 °C, the polymer C-51 was polymerized at 60 °C.

Molecular weights. The molecular weights of the copolymers were calculated from the ^1H NMR spectra (in *d*-chloroform) of the purified copolymers, by comparing the end-group peaks deriving from the initiator (2H at 5.07 ppm and 5H at 7.34 ppm) to appropriate side-chain peaks. The molecular weights calculated from the ^1H NMR spectra were always higher than theoretical molecular weights (Table 1). This is expected to derive from incomplete initiator efficiency and for block copolymers also from partial termination of the first block when the polymerization of the second block was started. The PTFEMA homopolymer was removed from the block copolymer samples, which increased their average molecular weights. The purification step in the block copolymer synthesis may also have removed block copolymers with smallest molecular weights from the samples, further increasing their molecular weights.

Table 1. Theoretical and experimental molecular weights of the PTFEMA/PDMAEMA copolymers.

Sample	Theoretical M_n^a (g/mol)	Experimental M_n (by ^1H NMR) (g/mol)
C-12	17200	22000
C-24	17400	22900
C-51	18600	24100
B-20	20800	39500
B-47	21100	37700

^a calculated for the monomer conversions, at which the polymerizations were stopped.

Reactivity ratio measurements of the TFEMA/DMAEMA monomer pair. The reactivity ratios of the TFEMA/DMAEMA pair were measured with the Jaacks method¹⁻³. The method involves the use of a large excess of one monomer (M_1) relative to the other one (M_2). The reactivity ratio of the monomer in excess is obtained from the linear logarithmic plot of monomer conversions:

$$r_1 = \frac{\ln \frac{[M_1]_0}{[M_1]}}{\ln \frac{[M_2]_0}{[M_2]}} \quad (1)$$

where $[M_i]_0$ and $[M_i]$ are the initial concentration of monomer i and the concentration of unreacted monomer i after a given polymerization time, respectively.

The Jaacks plots were generated from TFEMA/DMAEMA copolymerizations at 95:5 and 5:95 molar ratios. The polymerizations were conducted with CuBr/*N*-(*n*-pentyl)-2-pyridylmethanimine catalyst system, and toluene as solvent (1:1 v/v) at 90 °C (same conditions as in the other statistical copolymerizations of TFEMA and DMAEMA). The plots are presented in Figure 3 and Figure 4. From the plots, the reactivity ratios measured for the TFEMA/DMAEMA monomer pair were $r_{\text{TFEMA}} = 0.76$ and $r_{\text{DMAEMA}} = 0.81$. The values correspond to a rather random copolymerization with no tendency towards formation of blocks within the polymer chain.

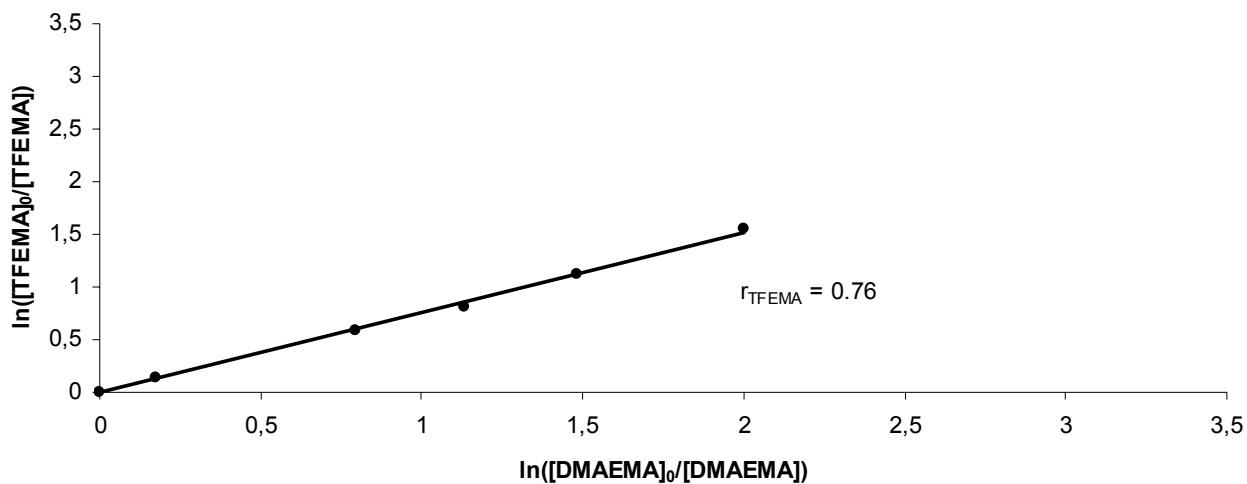


Figure 3. Jaacks plot of the copolymerization of TFEMA and DMAEMA (95:5).

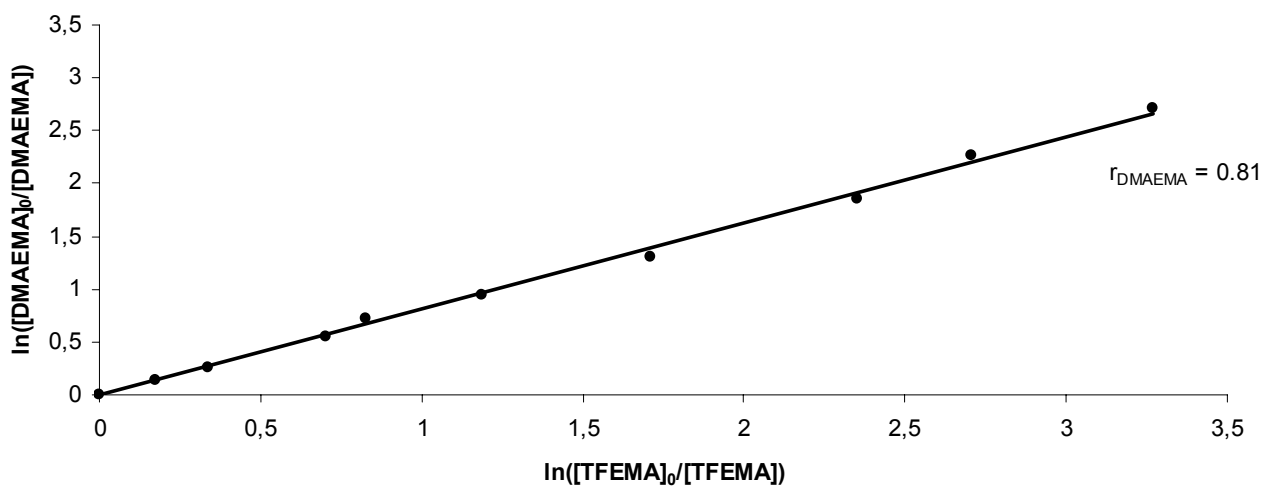


Figure 4. Jaacks plot of the copolymerization of DMAEMA and TFEMA (95:5).

The exponential decay curves of the spin-spin (T_2) relaxation time measurements.

Each point in the curves represents the height of the $-\text{CF}_3$ peak in the ^{19}F spectrum, as the number of pulses in the echo train is increased from 2 to 256. The used echo times (τ) are reported for each measurement separately in the figure captions.

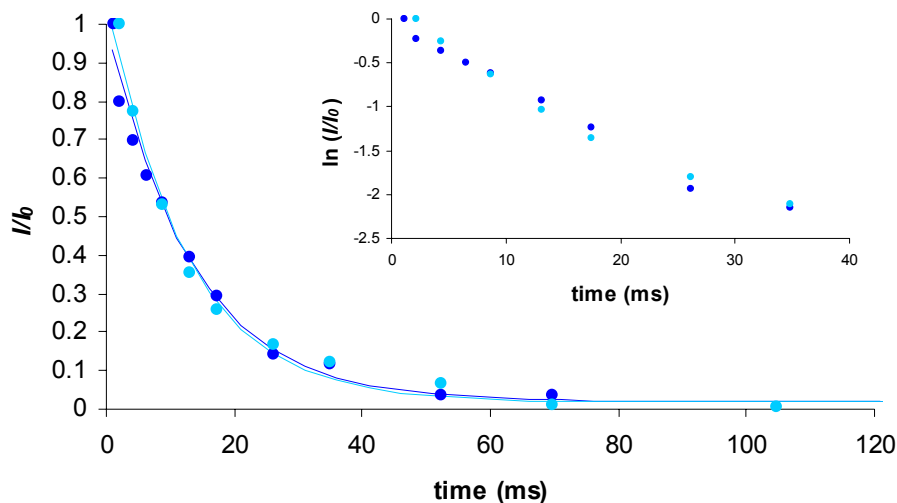


Figure 5. Spin-spin (T_2) relaxation time measurements for the 1 w/v-% C-12 solutions at pH 8 with exponential decay curves fitted. Dark blue: no salt, measured with $\tau = 250 \mu\text{s}$. $T_2 = 13 \text{ ms}$. Light blue: 0.25 M NaCl, measured with $\tau = 500 \mu\text{s}$. $T_2 = 12 \text{ ms}$.

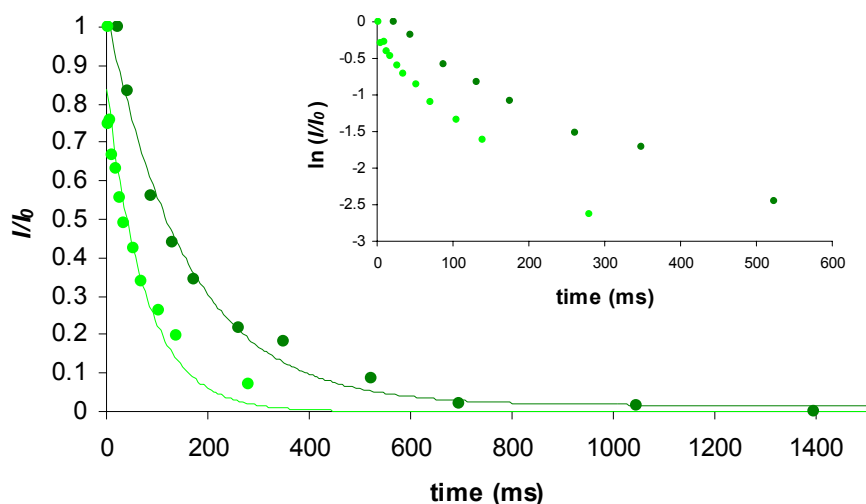


Figure 6. Spin-spin (T_2) relaxation time measurements for the 1 w/v-% C-12 solutions at pH 6.5-7.3 with exponential decay curves fitted. Dark green: pH 6.5, no salt, measured with $\tau = 5$ ms. $T_2 = 140$ ms. Light green: pH 7.3, 0.25 M NaCl, measured with $\tau = 500$ μ s. $T_2 = 76$ ms.

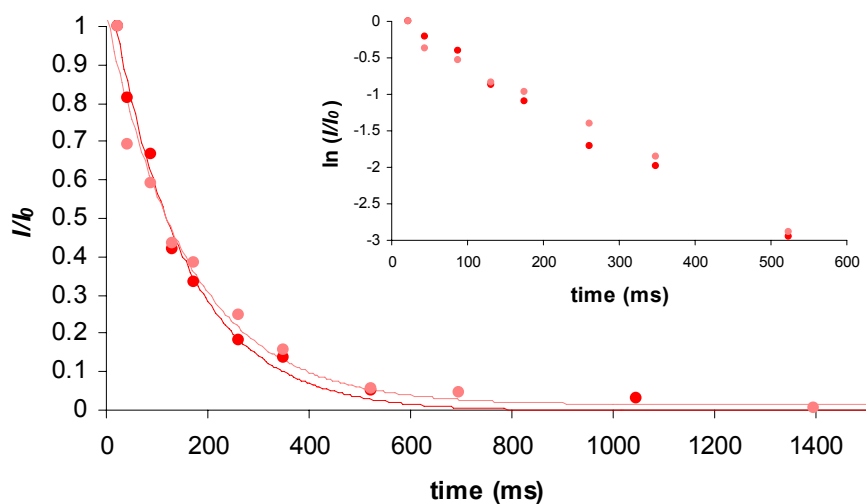


Figure 7. Spin-spin (T_2) relaxation time measurements for the 1 w/v-% C-12 solutions at pH 2 with exponential decay curves fitted. Dark red: no salt, measured with $\tau = 5$ ms. $T_2 = 140$ ms. Pink: 0.25 M NaCl, measured with $\tau = 5$ ms. $T_2 = 160$ ms.

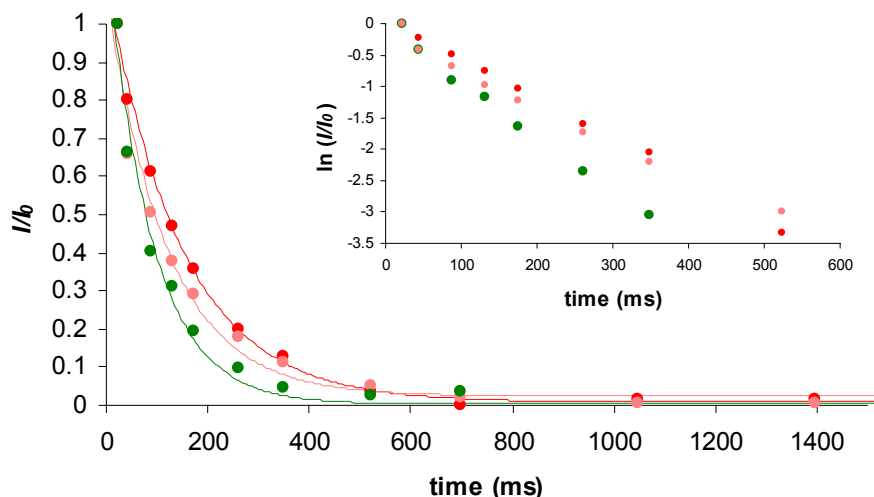


Figure 8. Spin-spin (T_2) relaxation time measurements for the 1 w/v-% C-24 solutions with exponential decay curves fitted. Green: pH 6.5, no salt, measured with $\tau = 5$ ms. $T_2 = 81$ ms. Dark red: pH 2, no salt, measured with $\tau = 5$ ms. $T_2 = 150$ ms. Pink: pH 2, 0.25 M NaCl, measured with $\tau = 5$ ms. $T_2 = 120$ ms.

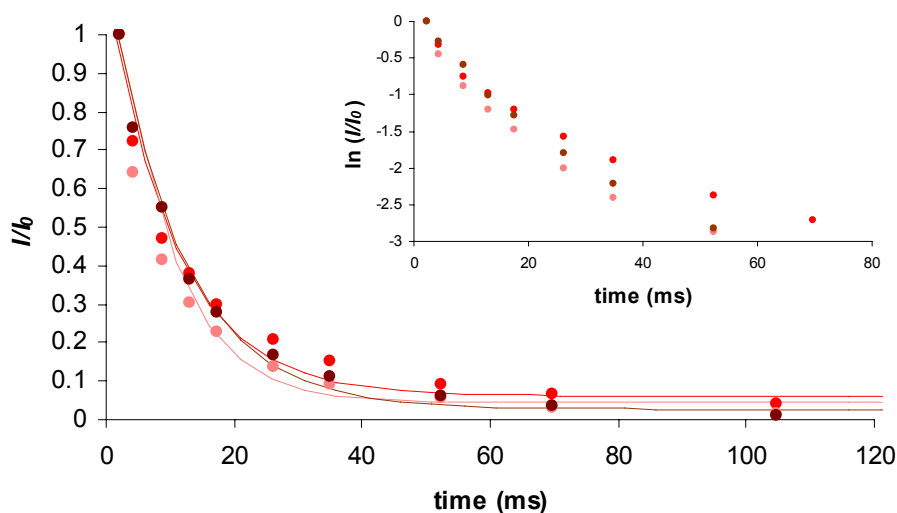


Figure 9. Spin-spin (T_2) relaxation time measurements for the 1 w/v-% C-51 and QC-51 solutions with exponential decay curves fitted. Dark red: C-51, pH 2, no salt, measured with $\tau = 500$ μ s. $T_2 = 11$ ms. Pink: C-51, pH 2, 0.25 M NaCl, measured with $\tau = 500$ μ s. $T_2 = 8.4$ ms. Brown: QC-51, 0.25 M NaCl, measured with $\tau = 500$ μ s. $T_2 = 11$ ms.

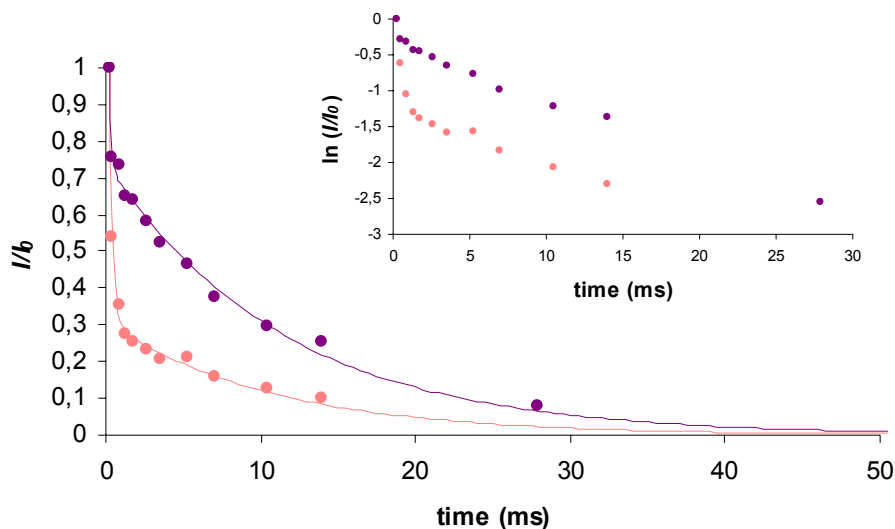


Figure 10. Spin-spin (T_2) relaxation time measurements for the 1 w/v-% B-20 and B-47 solutions with exponential decay curves fitted. Purple: B-20, measured with $\tau = 50 \mu\text{s}$. $T_2 = 69 \%$ 0.12 ms and 31 % 11 ms. Pink: B-47, measured with $\tau = 50 \mu\text{s}$. $T_2 = 86 \%$ 0.22 ms and 14 % 11 ms.

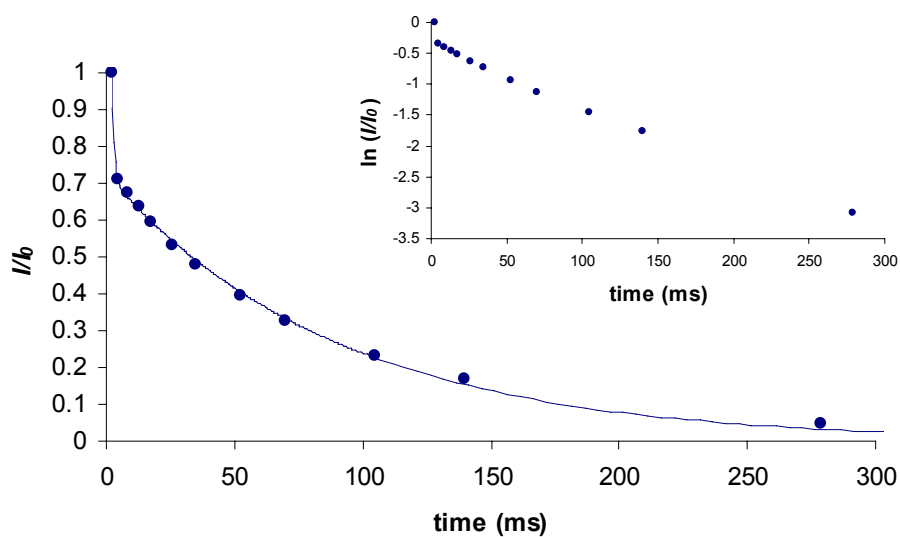


Figure 11. Spin-spin (T_2) relaxation time measurement for the 2.5 w/v-% QB-47 solution with exponential decay curve fitted. Measured with $\tau = 500 \mu\text{s}$. $T_2 = 89 \%$ 0.73 ms and 11 % 81 ms.

References

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