

## Self-Organization of Amphiphilic Copolymers into Nanoparticles: Study by $^1\text{H}$ NMR Longitudinal Relaxation Time

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### ABSTRACT

The aggregation and nanoparticle formation of a novel amphiphilic polymer **1** based on polyethylene glycol has been studied by  $^1\text{H}$  NMR longitudinal relaxation time ( $T_1$ ). The  $T_1$  of proton NMR, which may be associated with the mobility of molecular chains showed different trends when the amphiphilic polymer was dissolved in aqueous and organic solvents. It was observed that the  $T_1$  relaxation time of protons on hydrophobic chains decreases with the increase in concentration in aqueous media and stabilizes above the critical micelle concentration (CMC). The stabilization of  $T_1$  relaxation time of protons on hydrophobic chains in aqueous media occurs because of the aggregation of hydrophobic side chains in the core of nanospheres formed due to hydrophobic interactions. However, in organic solvent, the  $T_1$  of protons on hydrophobic as well as hydrophilic chain of amphiphilic polymer did

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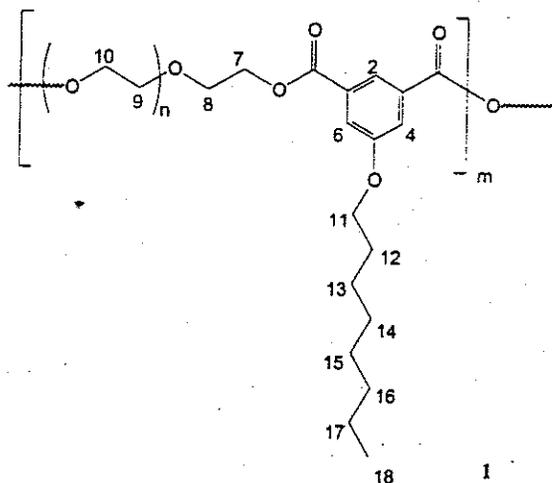


Figure 1. Structure of the PEG-based polymer.

## EXPERIMENTAL

### Materials

PEG-based amphiphilic copolymer poly[poly(oxyethylene1500)-5-octoxyisophthaloyl] (**1**) with a number average molecular weight of 20,000 Da (GPC) was synthesized by an earlier reported method.<sup>[10]</sup> The number 1500 represents the number average molecular weight of PEG block used to form the backbone chains of the copolymer. The copolymer **1** was freeze-dried before use. The solvents, deuterium oxide ( $D_2O$ ) and chloroform-*d* ( $CDCl_3$ ), were from Aldrich and used as received.

### Instrumentation

A 500 MHz Bruker NMR, Model-DRX500 equipped with B-VT2000 temperature controller was used for carrying out the  $^1H$  NMR and  $^1H$  NMR longitudinal relaxation studies ( $T_1$ ). The pulse program for water peak suppression is pre-saturation Fourier transform, while inversion-recovery Fourier transform was used for measuring  $T_1$ .

### Sample Preparation

The stock solution (2% w/w) was prepared by dissolving 0.090 g of the polymer **1** in 4.0 g of  $D_2O$  or  $CDCl_3$  in a scintillation vial of 20 mL capacity. This stock solution was used to prepare 10 solutions of different concentrations and transferred to 10 different 5 mm, 7" NMR tubes (0.4 mL). Each sample was degassed with nitrogen before sealing and left over night for thermal equilibrium.

## RESULTS AND DISCUSSION

The process of nanoparticle formation of the amphiphilic copolymer poly[poly(oxyethylene)oxy1500-5-octoxyisophthaloyl] (1) was studied using  $^1\text{H}$  NMR longitudinal relaxation time ( $T_1$ ) techniques. It was expected that the formation of these nanoparticles, viz. aggregation of the hydrophobic segments in different solvents would result in the restriction of the segmental motion and mobility of the polymer components. This restriction of the motion of polymer molecular chains would have significant effects on the NMR longitudinal relaxation or spin-lattice relaxation time ( $T_1$ ) of their protons.

Figure 2 shows the plot of the longitudinal relaxation time ( $T_1$ ) of selective protons, i.e., 2, 4, 6 of the aromatic ring and 12, 13-17, and 18 of the hydrophobic side chain of the amphiphilic copolymer 1 in  $\text{D}_2\text{O}$  solution at various concentrations (wt%). The plot shows that the  $T_1$ s gradually decrease in similar ways as the concentration of the solution increases and that they tend to level off as the concentration approaches 2 wt%. The greatest amount of change occurs in the very low concentration range, at approximately the CMC as determined by light scattering. This would indicate that the changes are associated with process of particle formation.

Under similar conditions as used in experiment shown in Fig. 2, we have also examined the effect of concentration on the  $T_1$ s of the PEG related protons, i.e., protons 7-10 on the hydrophilic segment of the polymer backbone chain. Unlike the behavior of the  $T_1$ s of the hydrophobic side chain shown in Fig. 2, the  $T_1$ s of the protons on the hydrophilic chain showed an initial increase and then a decrease in value with the increase in concentration (Fig. 3). The greatest changes again occurring at the very low concentrations at approximately the CMC value. The data shows considerable scatter, however, it is clear that there is a change in mobility near the CMC, which is indicative of particle formation.

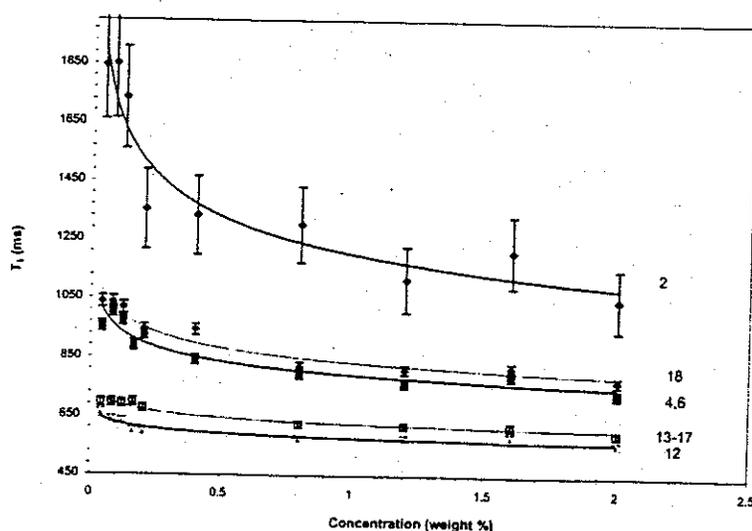


Figure 2. The concentration dependence of  $T_1$ s of the aromatic protons and the hydrophobic side-chain protons of 1 in  $\text{D}_2\text{O}$ .

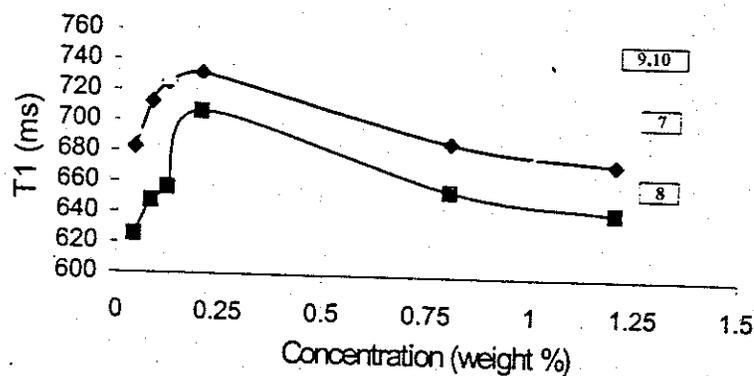


Figure 3. The concentration dependence of  $T_1$ s of the protons on the hydrophilic moiety of **1** in  $D_2O$ .

The relation time results of both the hydrophobic and hydrophilic portions of the amphiphilic copolymer indicate that there is restriction in mobility that may be associated with particle formation. The hydrophobic moieties would be expected to aggregate readily in aqueous solution and indeed show larger changes in relaxation times. The hydrophilic portion shows a more gradual restriction in mobility only close to the point of attachment to the hydrophobic aromatic ring (protons 7 and 8) but also throughout the length of the PEG portion of the backbone. This would indicate that the PEG portions still have some freedom of motion as may be expected with the hydrophilic nature of this structure.

We have further studied the effect of solvent on the process of particle formation of **1** by using chloroform as the solvent. In this solvent, the  $T_1$ s of all protons increased with

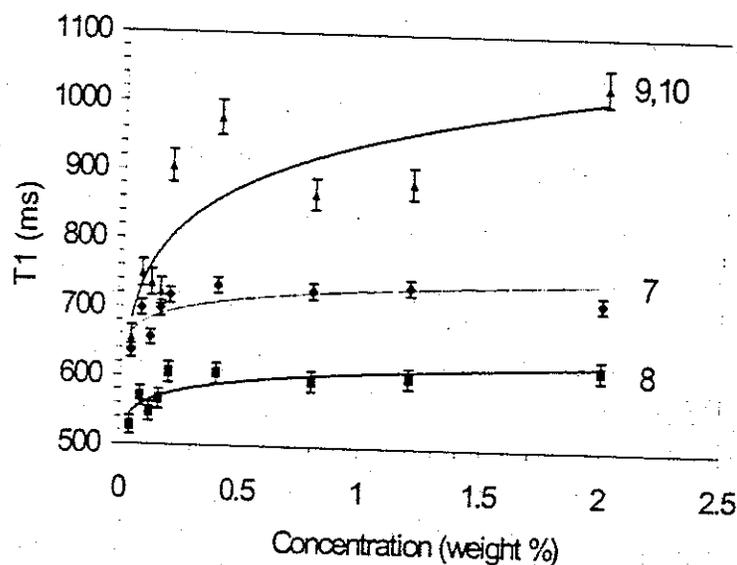


Figure 4. The concentration dependence of  $T_1$ s of the protons on the hydrophilic side chains of **1** in  $CDCl_3$ .