

SUPPORTING INFORMATION

Probing the Association of Triblock Copolymers with Supported Lipid Membranes using Microcantilevers

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The deduction steps to construct the model for calculation of association constant K_A .

The polymer-lipid interaction is actually the association of triblock copolymer with the SLBs on the cantilever surface, which is theoretically studied using a Langmuir isotherm model¹. The association process is shown as:



In equation above, S_{POPC} represents POPC bilayer, polymer represents the Pluronic, and K_A is the association constant, which allows us to compare the relative affinities of the different Pluronics towards the SLBs²⁻³. The following assumptions are made in the model: the cantilever surface is totally covered by SLBs before the addition of copolymers; the association of copolymers with the SLBs is monolayer adsorption; the association process reaches equilibrium at a certain time.⁴ As a result, the polymer-SLB interaction can be written as a associating/disassociating reaction rate:

$$k_A[Polymer](1 - \theta) = k_{-A}\theta \quad (5)$$

where θ is the fraction of the SLBs with attached polymer, and $(1 - \theta)$ represents the sites available for further polymer association. Defining K_A as the ratio of k_A over k_{-A} , the expression for θ is given as:

$$K_A = \frac{k_A}{k_{-A}} = \frac{\theta}{(1 - \theta)[Polymer]} \rightarrow \theta = \frac{K_A[Polymer]}{1 + K_A[Polymer]}$$

(S1)

Since θ is defined as the fraction of the SLB attached with polymer, two expressions for θ can be correlated, as follows:

$$\theta = \frac{\Delta Stress}{\Delta Stress_{max}} \rightarrow \frac{K_A[Polymer]}{1 + K_A[Polymer]} = \frac{\Delta Stress}{\Delta Stress_{max}}$$

(S2)

The following equation describes the relationship between polymer concentration and the surface stress change measured on cantilever:

$$\frac{1}{\Delta Stress} = \frac{1}{\Delta Stress_{max}} + \frac{1}{\Delta Stress_{max} K_A [Polymer]}$$

(S3)

$$\rightarrow \frac{[Polymer]}{\Delta Stress} = \frac{[Polymer]}{\Delta Stress_{max}} + \frac{1}{\Delta Stress_{max} K_A}$$

(6)

where $[Polymer]$ is the molar concentration of triblock copolymers. $\Delta Stress$ is the change of surface stress caused by polymer and $\Delta Stress_{max}$ is the maximum change in surface stress when the polymer saturates the surface. K_A is obtained from the plot of $[Polymer]/\Delta Stress$ with respect to $[Polymer]$.

Figure S1 shows the plots of $[Polymer]/\Delta Stress$ with respect to $[Polymer]$ for F68 and F98 at various temperatures. In each plot four data points are used to optimize the

linear data fitting. From the slope and intercept of each plot, the association constant K_A is calculated (Table 2). The values of K_A represent the relative solubility of each copolymer with the POPC SLBs, with the largest value corresponding to the highest solubility.

The deduction steps in free area model.

A free area model is used to characterize the lipid diffusion in a SLB.⁵⁻⁶ In this model, the lateral diffusion of molecules was considered to be a two-dimensional random motion. To move, a lipid needs to meet two requirements: a minimum empty surrounding area and a sufficient activation energy.⁷⁻⁸ Therefore, the diffusion coefficient can be affected by two possibilities:

$$D = D' p(a) p(E) \quad (7)$$

In Equation 7, $p(a)$ is the Boltzmann distribution of a lipid with minimum free surrounding area a_f and $p(E)$ is the probability that the activation energy is sufficient.

$$p(a) = \exp\left(-\frac{a_0}{a(T) - a_0}\right)$$

(S4)

$$p(E) = \exp\left(-\frac{E_a}{kT}\right) \quad (S5)$$

In the equations above, $a(T)$ is average lipid area, a_0 is critical area of lipid when it is closely packed, E_a is activation energy, and k is Boltzmann constant. Thus the average free area of lipids is $a_f = a(T) - a_0$. Detailed derivation of this model has been previously reported by Reits *et al.*⁹ In two dimensions, the preexponential factor D' is shown as:

$$D' = \delta^2/4\tau \quad (S6)$$

where δ is the distance between molecules and τ is the time for each movement. Therefore, the average velocity of molecular movement is $v = \delta/\tau$. The velocity v can be further related to the thermal energy through following equation.

$$E_k = \frac{1}{2}mv^2 \quad (S7)$$

The mass m can also be expressed by the average molecular weight M via $m = M/N_a$,

where N_a is Avogadro's constant. The distance δ is calculated through $\delta = [a(T)]^{\frac{1}{2}}$. Thus the preexponential factor D' is finally expressed as:

$$D' = \frac{\delta}{2\sqrt{2}\sqrt{m}} = \frac{1}{\sqrt{8}} \sqrt{\frac{kN_a a(T)T}{M}} \quad (S8)$$

In a two-dimensional SLB, the diffusion coefficient of lipids can be expressed as:

$$D = \sqrt{\frac{kN_a}{8}} \sqrt{\frac{T a(T)}{M}} \exp\left(\frac{-a_0}{a(T) - a_0} - \frac{E_a}{kT}\right)$$

(8)

The equation above is only valid for pure lipids. However, with the association of the triblock copolymer with the SLBs, the effects of the polymer on lipid diffusion must be considered, which are the decrease of free area and change of activation energy. Two parameters, average polymer area a_0^{poly} and molar ratio of polymer to lipid n , are introduced. The expressions for the average free area of lipids a_f and the average molecular weight M are corrected, as follows:

$$a_f = a(T) - a_0 - na_0^{poly} \quad (S9)$$

$$M = M_{lipid} + nM_{polymer} \quad (S10)$$

Substituting two equations above into Equation 8, the general expression for the diffusion coefficient of lipids, no matter whether polymer is present or not, is given by

$$D = \sqrt{\frac{kN_a}{8}} \sqrt{\frac{T a(T)}{(1-n)M_{lipid} + nM_{polymer}}} \exp\left(\frac{-a_0}{a(T) - a_0 - n a_0^{poly}} - \frac{E_a}{kT}\right)$$

(9)

The values of parameters in the equations above are estimated based on their values in literatures. The activation energy E_a and molar ratio of polymer to lipid n are fitting parameters, obtained from nonlinear least square fitting. Figure 6 shows the fitting of the free area model to the experimental data, and Table 3 gives the molar ratio of polymer over lipid n .

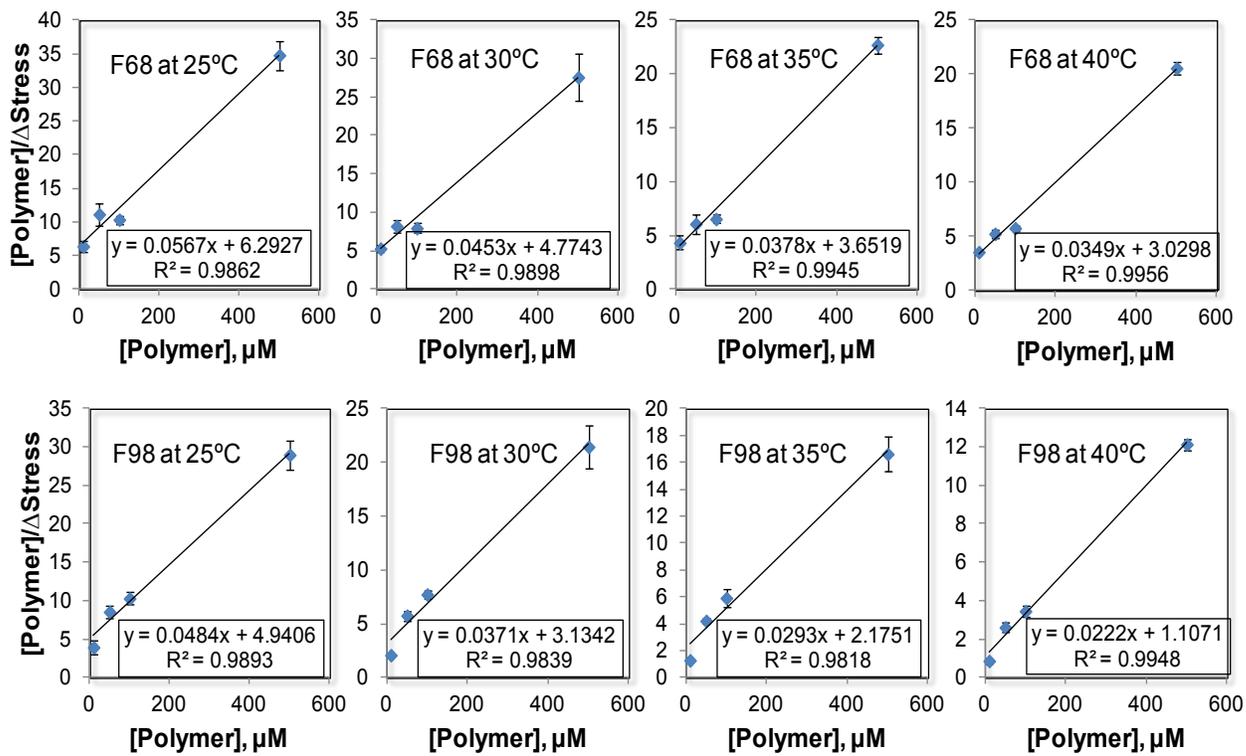


Figure S1. Determining the association constant K_A for the copolymers F68 (A) and F98 (B) at various temperatures. Experimental results for $[Polymer]/\Delta Stress$ is plotted with respect to $[Polymer]$ and fit to Equation 6. The equations for trend lines and R-squared values are shown.

Reference

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