

Supplementary Material

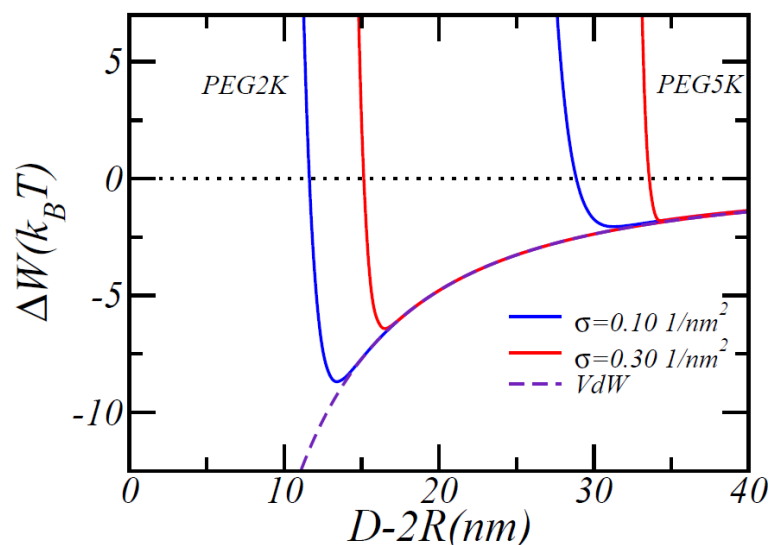


Figure S1. Effect of surface coverage on the free energy.

Figure S1 shows the free energy versus separation between two microbubbles and is similar to figure 3 in the main text. It shows the free energy for different values of the surface coverage for both PEG 2K and PEG 5K layers. The number of PEG molecules per unit area or surface coverage are centered around the experimental value of $\sigma = 0.20 \text{ nm}^{-2}$. With increasing surface coverage, the polymers tend to experience more excluded volume interactions. To avoid the increased excluded volume interactions, the polymers tend to stretch more. Consequently the polymer layer becomes more extended and hence two microbubbles coated with a polymeric shell will interact with each other at larger separations for microbubbles with higher polymer surface coverage. Likewise due to the increased density the steric repulsion increases more steeply with increasing surface coverage (more noticeable for PEG 5K). Notice that the range at which the steric repulsions increase for PEG 2K and PEG 5K is around 5 nm, which is insufficient to change the size of the free energy minimum significantly. PEG 2K layers do not possess sufficient range to overcome the VdW attraction. Therefore microbubbles with a PEG 2K shell will remain unstable irrespective of how many PEG 2K polymers make up the polymeric shell.

Microbubbles with polymeric shells of PEG 5K have sufficient range to be able to (marginally) stabilize the microbubbles against aggregation.

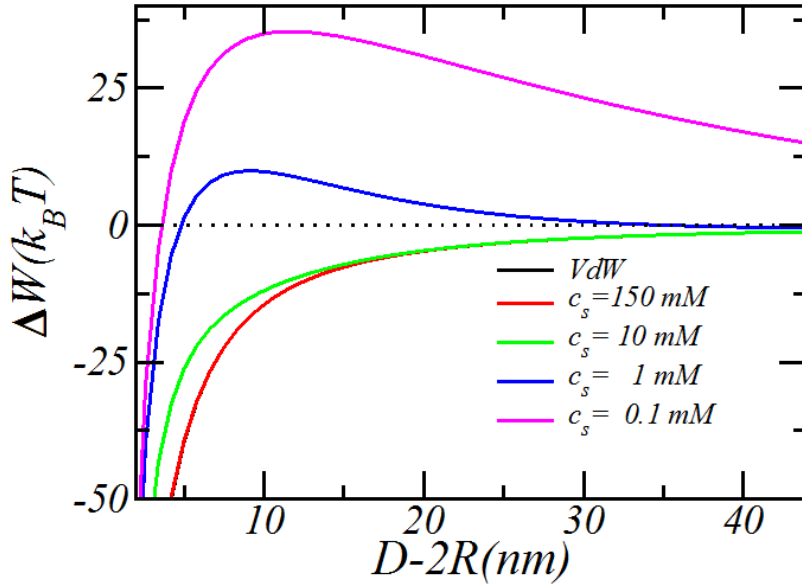


Figure S2. Effect of salt concentration on the free energy. $\Delta W = W_{Elect} + W_{vdW}$.

Figure S2. shows the effect of salt concentration upon the free energy. To demonstrate the effect of salt on the free energy for two interacting microbubbles most clearly, the free energy is the sum of the VdW attraction and electrostatic repulsions only: $\Delta W = W_{Elect} + W_{vdW}$. The effect of the steric repulsions from the PEG polymer layer is omitted. For the experimental salt concentration of $c_s = 150$ mM, the electrostatic repulsions are very small. The free energy curve for high salt concentrations is indistinguishable from the free energy arising solely from the VdW attractions. For lower salt concentrations of $c_s = 1$ mM to 0.1 mM, the range and size of the electrostatic interactions become large enough to overcome the VdW attraction and prevent aggregation of the microbubbles. The surface potential has a value of $\psi_0 = 8$ mV, which is in the range of the measured zeta-potentials. A lower

surface potential will reduce the strength of the electrostatic repulsions. For example for $\psi_0 = 6 \text{ mV}$ and a salt concentration of $c_s = 1 \text{ mM}$ the free energy has a maximum of only $0.6 \text{ k}_B\text{T}$ compared to the $10.2 \text{ k}_B\text{T}$ free energy barrier for an electrostatic surface potential of $\psi_0 = 8 \text{ mV}$. Hence microbubbles (with a charged lipid shell) of radius $R = 1 \text{ }\mu\text{m}$ having an electrostatic surface potential of $\psi_0 = 8 \text{ mV}$ can be stabilized in a $c_s = 1 \text{ mM}$ salt concentration solution by only electrostatic repulsions, whereas microbubbles with a lower surface potential can not be stabilized by electrostatic forces only. However, combining the electrostatic repulsions of $\psi_0 = 6 \text{ mV}$ at $c_s = 1 \text{ mM}$ with steric repulsions will be enough to increase the free energy barrier and reduce the free energy minimum to such a degree as to stabilize the microbubbles coated with PEG 5K as well as microbubbles having a PEG 2K polymer shell. So provided that the salt concentration is sufficiently low, electrostatic interactions are able to generate sufficient additional repulsions to overcome the VdW attractions and stabilize the microbubbles and prevent aggregation.