

suspensions was determined by isothermal titration calorimetry (ITC; Thermometric AB, Sweden). Briefly, 2 mL of the liposome suspension solution was placed in an ampule. A series of 150-mL buffer solutions was then titrated into the dispersion lipid vesicle suspension using a Hamilton microliter syringe at 30-min intervals after the ampule and the heat sink had reached thermo-equilibrium. The lipid vesicle suspension was titrated 5 times per experiment. All experiments were performed at temperatures of 298 K and 310 K, respectively.

Dilution heats of Tween-grafted lipid vesicle suspensions with the number density of the lipid vesicle suspension can be generally expressed as a function of a second-order polynomial as in Eq. 1:

$$\frac{d \frac{q}{Nk_B T}}{d\rho} \cong \frac{d \frac{E}{Nk_B T}}{d\rho} = b_2 + b_3\rho + b_4\rho^2 \quad (1)$$

For an open liquid system, pressure changes and the titration volume are neglected in the system total volume. The observed dilution heat of each titration is comparable to the internal energy change. Furthermore, the internal energy change can be expressed by the virial coefficient and the number density in Eq. 2:

$$\frac{E}{Nk_B T} = \frac{3}{2} - T \sum_{i=1}^{\infty} \frac{1}{i} \frac{dB_{i+1}}{dT} \rho^i \quad (2)$$

Comparing Eq. (1) with Eq. (2) reveals that the coefficient of the dilution heat polynomial can be affiliated with the virial coefficients as in Eq. 3:

$$b_2 = -T \frac{dB_2}{dT} \quad (3)$$

According to statistical mechanics, the relation between the second virial coefficient and the interaction potential energy function $U(r)$ is

$$B_2(T) = -2\pi \int_0^{\infty} \left[\exp\left(-\frac{U(r)}{k_B T}\right) - 1 \right] r^2 dr \quad (4)$$

and if a square-well energy potential function is picked and plugged into Eq. 4, then Eq. 3 can be rewritten as:

$$b_2 = -T \frac{dB_2}{dT} = -B_0(\lambda^3 - 1)e^{\frac{\epsilon}{k_B T}} \left(\frac{\epsilon}{k_B T} \right) \quad (5)$$

$$b_2 / B_0 = (\lambda^3 - 1)e^{\frac{\epsilon}{k_B T}} \left(\frac{\epsilon}{k_B T} \right) \quad (6)$$

where $B_0 = (16/3) \pi R_{HS}^3$, $\lambda = (2R_H + \sigma) / 2R_{HS}$, and σ and ϵ denote the width and depth (or energy barrier) of the square-well energy potential function, respectively. In our experimental system, the value of b_2/B_0 can be described qualitatively from the interaction potential ϵ between Tween-grafted lipid vesicle suspensions.

RESULTS AND DISCUSSION

Zeta Potential Measurement

The zeta potential (ξ -potential) of PC lipid vesicles was measured by incorporating different quantities of Tween 80 or Tween 20 surfactants into the PC bilayer. Experimental results indicate that egg-PC lipid vesicles possess negative charges at pH 7.4. This finding is consistent with those of Carrion et al.²³ and McLaughlin et al.²⁴ Which indicated that there is a weak electrostatic repulsive force between PC lipid vesicles at pH 7.4. Table 1 summarizes the effect of Tween surfactants on the zeta potential of PC liposomes. Incorporation of different amounts of Tween surfactants into the PC bilayer of lipid vesicles did not significant impact the zeta potential at 298 K.

Interaction Between PC Lipid Vesicles

The effect of Tween surfactants on the overall interaction between lipid vesicles (intervescicle interaction) was investigated using the interaction potential. The value and the sign of the second virial coefficients of the interaction (intervescicle interaction) between