

Supplementary Information

The force due to Lennard-Jones potential between the bead-bead and the bead-wall particle is computed by

$$\mathbf{F}_{\text{LJ},i} = \begin{cases} 24\varepsilon \sum_{j=1}^N 2 \left(\frac{\sigma^{12}}{r_{i,j}^{13}} \right) - \left(\frac{\sigma^6}{r_{i,j}^7} \right)^6 \hat{\mathbf{r}}_{i,j} & \text{if } r_{i,j} < r_{\text{cut}} , \\ 0 & \text{if } r_{i,j} \geq r_{\text{cut}} \end{cases}, \quad (\text{S1})$$

where σ and ε are the length and energy scales of the potential, respectively, and $r_{\text{cut}} = 2^{1/6}\sigma$ is the cut-off distance which ensures that only repulsive interaction takes place when two beads are closer than r_{cut} . Further, $r_{i,j}$ denotes distance between the bead i and the bead j , and $\hat{\mathbf{r}}_{i,j}$ indicates the unit vector of the displacement vector $\mathbf{r}_{i,j}$ of the particle i referred to the particle j , i.e., $\mathbf{r}_{i,j} = \mathbf{r}_i - \mathbf{r}_j$.

The bond stretching force due to the connectivity between the bead i and each of its adjacent beads, $i-1$ and $i+1$, is given by

$$\mathbf{F}_{\text{bond},i} = -K_{\text{bond}}(r_{i,i-1} - \sigma_0)\hat{\mathbf{r}}_{i,i-1} - K_{\text{bond}}(r_{i,i+1} - \sigma_0)\hat{\mathbf{r}}_{i,i+1}, \quad (\text{S2})$$

where K_{bond} is the bond-stretching force constant and σ_0 is the segment length. In our simulations, we have chosen $K_{\text{bond}} = 1000 k_B T / \sigma_0^2$. Here k_B represents the Boltzmann constant and T is the temperature of the fluid.

The force due to bending interaction between the particle i and the two neighboring particles, $i-1$ and $i+1$, is calculated by

$$\mathbf{F}_{\text{bend},i} = -K_{\text{bend}}(\phi - \phi_a) \left[\frac{1}{r_{i-1,i}} \frac{\mathbf{r}_{i-1,i} \times (\mathbf{r}_{i+1,i} \times \mathbf{r}_{i-1,i})}{|\mathbf{r}_{i-1,i} \times (\mathbf{r}_{i+1,i} \times \mathbf{r}_{i-1,i})|} + \frac{1}{r_{i+1,i}} \frac{\mathbf{r}_{i+1,i} \times (\mathbf{r}_{i-1,i} \times \mathbf{r}_{i+1,i})}{|\mathbf{r}_{i+1,i} \times (\mathbf{r}_{i-1,i} \times \mathbf{r}_{i+1,i})|} \right], \quad (\text{S3})$$

where K_{bend} is the bending rigidity constant which restores the angle ϕ to an equilibrium angle $\phi_a = \pi$; here ' $\times$ ' indicates the cross product. K_{bend} is related to the persistence length, P , of dsDNA and its value is $K_{\text{bend}} = P k_B T / \sigma_0$.

The random force due to the thermal fluctuations in the fluid environment is taken as a Gaussian random variable with the mean and variance given by

$$\begin{aligned} \langle \mathbf{F}_{\text{ran},i}(t) \rangle &= 0, \\ \langle \mathbf{F}_{\text{ran},i}(t) \mathbf{F}_{\text{ran},j}(t') \rangle &= 2\Gamma_{\text{bare}} k_B T \delta_{ij} \delta(t-t') \end{aligned} \quad (\text{S4})$$

where δ_{ij} and $\delta(t-t')$ are the Kronecker and Dirac delta functions, respectively. Here we replace Γ_{bare} with Γ when HI are neglected.

Table S1. Important simulation parameters.

Parameter	Value	Reference quantity	Dimensionless value
Equilibrium length of the segment, σ_0	$\sigma_0 = 10 \text{ nm}$	σ_0	$\sigma_0^* = 1$
Lattice grid size, Δx	$\Delta x = 10 \text{ nm}$	σ_0	$\Delta x^* = 1$
Density of water, ρ_o	$\rho_o = 1000 \text{ kg/m}^3$	ρ_o	$\rho_o^* = 1$
Viscosity of water, μ	$\mu = 10^{-3} \text{ N-s/m}^2$	$\mu_{\text{ref}} = \frac{\mu}{\mu^*}$	$\mu^* = 7$
Temperature	$T = 300 \text{ K}$	—	—
Energy, $\varepsilon = k_B T$	$k_B T = 4.14 \times 10^{-21} \text{ J}$	$k_B T$	$k_B T^* = \varepsilon^* = 1$
LB time step, Δt	$\Delta t = 6.9 \times 10^{-10} \text{ s}$	$\tau_{\text{ref}} = \frac{\mu_{\text{ref}} \sigma_0^3}{k_B T}$	$\Delta t^* = 0.02$ (LD time step, $dt^* = 0.01$)
Friction coefficient, Γ [From Equation (13) of Reference [21]]	$\Gamma = 4.61 \times 10^{-11} \text{ N-s/m}$	$\Gamma_{\text{ref}} = \mu_{\text{ref}} \sigma_0$	$\Gamma^* = 32$ ($\Gamma_{\text{bare}}^* = 40$)
Effective charge on each bead, q_i	$q_i = 1.42 \times 10^{-18} \text{ C}$	$q_{i,\text{ref}} = 1e$, where e is the proton charge	$q_i^* = 9$
Applied voltage, $\Delta \varphi$	$\Delta \varphi = 120 \text{ mV}$	$\Delta \varphi_{\text{ref}} = k_B T / e$	$\Delta \varphi^* = 4.7$