Abstract

Bacteria such as *Escherichia coli* perform a biased motion in a heterogeneous spatial chemical environment. This motion, commonly known as chemotaxis, has generated a substantial research interest among scientists over the last few decades. The movement of the motile bacteria resembles the drift-diffusion motion observed in gases, or in electrons in a metal bar. However, unlike the pure thermodynamic genesis of the Brownian motion, bacteria mimic a random motion using their sophisticated chemosensory modules, biochemical circuits for adaptation, and the flagellar motor modules. Using chemotaxis, these single cellular organisms place themselves in a favorable spatio-temporal localization.

The present dissertation develops a predictive modeling scheme for quantifying the chemotactic drift in response to three different spatial/spatio-temporal ligand concentration gradients, namely, the spatial exponential profile, the diffusive step profile, and the spatial exponentiated sinusoidal profile. The first model developed for the steady-state behavior explains and validates the experimental observations. The second model was built on the basis of the first model to extend the theory to transients. The successful prediction of *run-time* modulation, the Brownian-like trajectory, *tumbling* angle, and the measured drift velocity validated the theory developed in this dissertation.

Experiments were designed in the microfluidic channels to generate the controlled spatial or spatio-temporal ligand concentration gradients. The bacterial motion was captured using a time-lapse microscopy and an image processing based estimation algorithm was developed to measure the drift velocity from these observed trajectories. For the proof of the concept, Monte Carlo simulation algorithms were also designed to generate the Brownian-like motion trajectories on a digital computer. The convergence of the theoretical prediction, simulation, and experimental data provided the conclusion of the dissertation.

Keywords: Chemotaxis; *Escherichia coli*; drift; microfluidic experiment; steady-state analysis; transient analysis; bimodal analysis.