JPSJ News and Comments 17, 08 (2020) https://doi.org/10.7566/JPSJNC.17.08

Brownian Motion Confined in a Brownian Surface

Shigeyuki Komura (Department of Chemistry, Tokyo Metropolitan University)

Published July 27, 2020

A researcher has developed a new theory to describe the Brownian motion of a small object that is confined in a fluctuating random surface, such as a biological membrane. The effective diffusion coefficient is shown to provide a new dynamical contribution.

Owing to the recent advances in high-precision imaging techniques, scientists are able to directly observe the Brownian motion of a protein molecule embedded in a biological membrane. This type of membrane typically consists of a thin lipid bilayer, and it can be regarded as a two-dimensional (2D) fluid sheet. Another important feature of this type of lipid membrane is its high flexibility. Thus, the membrane can exhibit large out-of-plane shape fluctuations that can be experimentally measured [1].

What is the lateral diffusion behavior of proteins confined in such a highly fluctuating environment? Recently, the coupling of protein diffusion to the shape of the membrane surface has become a subject of active study, and various theoretical and experimental studies have been performed. Interestingly, previous theories have predicted that the effective diffusion coefficient of a particle immersed in a fluctuating membrane is smaller than that in a flat membrane.

On a fluctuating random membrane, a moving object needs to travel a larger distance between two points in a three-dimensional space because the trajectories are constrained on a rough surface rather than on a flat one (see Fig. 1). This is called the "geometrical contribution," which has been well explained in the previous studies. In an optical microscope experiment, one can only capture a 2D projection of the true particle motion over the membrane surface.

Recently, Ohta revisited the problem of lateral diffusion on a random surface by using a new theoretical approach [2]. A key technique in his formulation was to employ a Lagrange multiplier in the Langevin equation for the particle to take into account the constraint that it always sits on the fluctuating surface. With this mathematical technique, the theoretical framework of the problem has been established without any ambiguity.

In this new formulation, Ohta calculated the mean square displacement for the lateral diffusion of a Brownian particle and obtained the effective diffusion coefficient. First, the abovementioned geometrical contribution, which results in a reduced diffusion coefficient on a projected plane, was reproduced. Second, and most importantly, Ohta also found a new "dynamical contribution" that arises from the velocity correlation of the fluctuating surface.

In the paper, the two-time velocity correlation function of a fluctuating membrane surface has been evaluated in both the presence and absence of hydrodynamic interactions mediated by the surrounding bulk fluid. Using this result, Ohta then derived a self-consistent equation to determine the effective diffusion coefficient. The main conclusion was that the newly found dynamical contribution increases the effective diffusion coefficient as opposed to the geometrical contribution [2].

Fig. 1. Image for Brownian motion of a particle confined in a fluctuating random surface.

What is then the overall effect on the lateral diffusion coefficient owing to these two contributions? According to the numerical estimate of the effective diffusion coefficient, its reduction compared to that of a flat surface is diminished. Nevertheless, the net reduction is still 20–30%, which should be taken into account for experimental data analysis. Importantly, the dynamical contribution also depends on the dynamical properties of the surrounding bulk fluid, such as its viscosity.

This study on the Brownian motion on a fluctuating surface by Ohta opens up several new research areas for the future. In the recent years, many attempts have been made to quantify the non-equilibrium properties of biological systems by measuring the fluctuations at different levels and scales [1]. The work by Ohta clearly shows that the Brownian motion of a particle and the surface out-of-plane fluctuations are coupled in a non-trivial and an interesting way.

REFERENCES

[1] H. Turlier, D. A. Fedosov, B. Audoly, T. Auth, N. S. Gov, C. Sykes, J.-F. Joanny, G. Gompper, and T. Betz, Nat. Phys. **12**, 513 (2016).
[2] T. Ohta, J. Phys. Soc. Jpn. **89**, 074001 (2020).

Shigeyuki Komura obtained a Ph.D. in Physics from The University of Tokyo in 1993 and subsequently spent one year at the Tokyo Institute of Technology, three years at the Kyoto University, and five years at the Kyushu Institute of Technology. Since 2000, he has been at the Department of Chemistry, Tokyo Metropolitan University. The main research topic of his group is non-equilibrium physical chemistry of biological and soft matter, such as microrheology, micromachines, and active matter.

News and Comments on "**Brownian Motion on a Fluctuating Random Geometry**" [T. Ohta, J. Phys. Soc. Jpn. **89**, 074001 (2020)]