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Velocity correlation of a lipid in the lipid-bilayer membrane at the equilibrium

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The velocity correlation function (VCF) of a tracer particle decays away as $t^{-d/2}$ as the time $t$ tends to the infinity in a $d$-dimensional equilibrium fluid[1]. The Brownian particle — a larger impurity particle — also has this long time tail[2]. A biomembrane is a two-dimensional (2D) fluid surrounded with three-dimensional fluids. A membrane protein can be regarded as a Brownian particle[3]. Sera & Rubi[4] showed theoretically that both $t^{-1}$ and $t^{-3/2}$ appear in its velocity correlation[4]. This is reasonable, considering that the momentum on the membrane spread out into the outer fluids. Seki & Komura[5] obtained similar results in a more simple way by introducing a phenomenological momentum relaxation time $\tau$ which represents coupling strength between the membrane and the outer fluids. The VCF of the membrane protein was found to decay as $e^{-t/\tau}t^{-3/2}$ or $e^{-t/\tau}t^{-1}$ in the case of the strong- or the weak-coupling limits, respectively.

We study the VCF of the lipid molecule not a membrane protein. We assume that the lipid-bilayer membrane is a compressive 2D Newtonian fluid with the bending rigidity. It fluctuates about the equilibrium in the fluids on its both sides. Using unsteady Stokes approximation, we obtain the Eulerian VCF, $\langle v(k, t) \cdot v(k', t') \rangle$, with the aid of the linear response theory[6]. Here, the angular brackets represent the equilibrium ensemble average, while $v(k, t)$ denotes the Eulerian velocity field with $k$ representing the wave number vector.

Writing $V(t)$ for a lipid molecule velocity, apart from the fast decaying term, we have

$$\langle V(t) \cdot V(0) \rangle \propto D(t) \equiv \int_0^{k_U} dk e^{-D_0 k^2 t} \langle v(k, t) \cdot v(k, 0) \rangle \quad (1)$$

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in terms of the mode-coupling theory. Here, \( k_U \) is a upper cutoff wave number and \( D_0 \) is a 'bare' diffusion coefficient, which is independent of the hydrodynamics. We can evaluate its value in terms of the vacancy assisted diffusion[7].

Integrating right-hand side of (1) numerically by use of typical values, we obtain results shown as crosses in Fig.1. Two dotted lines with the slope of \(-1\) and \(-\frac{3}{2}\) are shown as guides. We can find that the VCF shifts from \( t^{-1} \) to \( t^{-\frac{3}{2}} \) as \( t \) increases. We are now studying which factor gives the time around which the transition takes place.

![Figure 1: The behaviour of \( D(t) \)](image)

References


