FLUCTUATION IN LIVING CELLS: EFFECT OF FIELD FLUCTUATION
AND ASYMMETRY OF FLUCTUATION

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Summary

The electric potential in living cells of paramecium shows large spontaneous fluctuation, which consists of basic fluctuation and spikelike fluctuation. The spikelike fluctuation triggers transient reversal of ciliary beating and causes discontinuous change of the swimming direction. A positive shift of the basic potential increases the probability of the spikelike fluctuation. The spike is generated by opening of electric field-sensitive channels in the cell membrane. A differential equation is proposed to describe the probabilistic behavior of these channels in a fluctuating electric field. The fluctuating field increases the average rates of open-close transitions of channels and shifts the average opening probability towards 1/2. The open-close fluctuation in an assembly of the channels has asymmetry with respect to time reversal. Free energy is continuously consumed for generation of the spikelike fluctuation. The proposed equation which contains fluctuating quantities in exponential terms has a definite physical basis and is useful for the analysis of stochastic processes in a fluctuating field.

1. Introduction

Living cells do not always show deterministic behavior but sometimes show probabilistic behavior. Paramecium cells, for example, swim straight and change the swimming direction discontinuously. The time interval of the discontinuous change of swimming direction has nearly an exponential distribution, suggesting that it happens as a result of stochastic processes in the cell. The average time interval or the average frequency of directional changes is regulated depending on the environmental condition, and this regulation makes possible the chemotaxis and thermotaxis of paramecium cells.1)
Paramecium cells have a large number of cilia on their cell surface and swim by beating these cilia. The discontinuous change of swimming direction is caused by transient reversal of the beating direction of cilia, which is initiated by depolarization of the electric potential in the cell. Recently, it was found that the electric potential in the cell has a large spontaneous fluctuation and a spikelike fluctuation induces the reversal of ciliary beating. The fluctuation is not simply a thermal one but produced by consuming free energy.

In this paper, we describe the characteristic features of the potential fluctuation in paramecium cells and propose a differential equation to express the process of amplification of fluctuation. This equation is generally useful to describe a state fluctuation of molecules in a fluctuating field. Nonlinear effects of the fluctuating field give remarkable characters to the solution of the equation. The results of the computer analyses of the equation are compared with experimental data.

2. The Potential Fluctuation in Living Cells of Paramecium

The electric potential in a living cell of paramecium can be measured by inserting a microelectrode into the cell fixed on a glass plate under an optical microscope. The potential is about -30 mV on the average, but it has a large spontaneous fluctuation even without any external stimuli, as shown in Fig. 1.

Fig. 1. A record of the fluctuating electric potential in a paramecium cell in a stationary state.

The fluctuation apparently consists of two components, conventionally