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Functional Roles of Noise in Nonlinear Nonequilibrium Systems

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It is common knowledge in physics that noise breaks the order and hides essential properties of physical systems. On the other hand, noise plays surprising roles in nonlinear nonequilibrium systems. In some cases, it reveals essential properties and produces order, especially in living systems where functional roles of noise are found.

Noise is despised in physics. Experimental physicists have taken great pains in eliminating noise from data. Also in engineering systems, it has been recognized that noise decreases function and quality. Therefore, efforts to reproduce an original signal from an observed one buried in noise were made.

However, it has been clarified over the last three decades that there are cases in which noise enhances functions in nonlinear nonequilibrium systems. The representative example that has attracted the most attention in physics and engineering is stochastic resonance [1]. Stochastic resonance is a phenomenon in which a signal below a threshold of detection can be detected by adding noise. There is a maximum signal-to-noise-ratio because a noise that is too strong hides the signal again. It is also known that synchronization between spatially-coupled oscillators can be enhanced by adding noise [2]. This phenomenon is called stochastic synchronization. Thus, the fact that noise can boost a signal and make order has had a big impact on science.

Influence of noise for self-organized ordered structures in spatially extended systems, which is called *dissipative structures*, are also studied. In particular, noise effect research on ac-driven electroconvection (EC) of nematic liquid crystals (NLC) have been performed for many years. When a voltage beyond a threshold V_c is applied to an NLC system, a transition from the electric conduction to EC where convective flow transports impurity ions occurs. EC ordered structures can be easily observed using the optical properties of NLC, as shown in Fig. 1(a). Various types of self-organized structures appear owing to the nonlinear interaction between convective flow and molecular orientation of NLC, as shown in Figs. 1(b) and 1(c). These properties provide benefits for the research of dissipative structures. Furthermore, the most important benefit for the research of noise effects is that the control parameter is voltage applied to the NLC. One can superimpose noise on the ac-voltage of which the characteristics are controllable.

In the research of noise effects for EC, the shift dependence of the threshold voltage V_c on noise intensity has been investigated. V_c can be easily measured in experiments, and the theory for the transition to EC around V_c has already been established. Therefore, the shift of V_c is suitable for investigating noise effects in EC. Past research has revealed that V_c under white noises with an intensity V_N can be described as

$$V_c^2 = V_{c0}^2 + bV_N^2, \qquad (1)$$

where V_{c0} is a threshold voltage for no noise and b is a positive constant. The fact that V_c increases by adding noise could be theoretically explained. This result, which means that the noise impedes feedback for the self-organization, can also be intuitively understood. In contrast to the past research in which white noises with a correlation time $\tau_N \sim 0$ were used, Huh et al. recently investigated the threshold shifts for colored noises of which τ_N is finite and controllable [3]. There are two characteristic times in EC: the charge relaxation time τ_σ, and relaxation time τ_d of the nematic director. Huh et al. took notice of the case in which τ_N is comparable to τ_σ. Their new result revealed that the constant b in Eq. (1) can be modified as

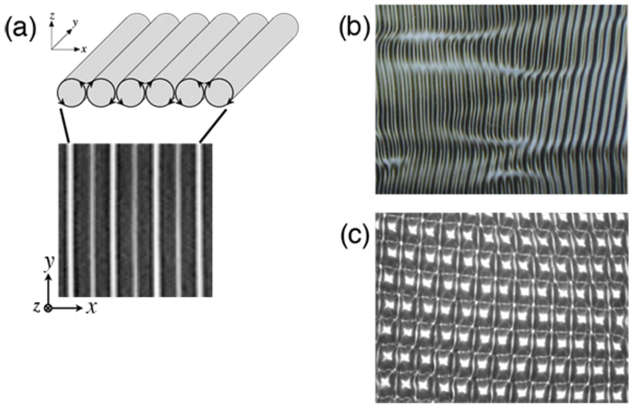

Fig. 1. Electroconvective patterns in a nematic liquid crystal. (a) Primary convective pattern known as the Williams domain. (b) Fluctuating Williams domain. (c) Grid pattern.

$$b_{\mathrm{mod}} = b[1 - h(\tau_N/\tau_\sigma^m)], \qquad (2)$$

where b, h, and m are positive constants. This result is remarkable because for $\tau_N > \tau_\sigma{}^m/h$, b_{mod} can become negative, i.e., V_c decreases by adding colored noise. It was also found that transition voltages to chaotic and higher-order patterns such as fluctuating the Williams domain [Fig. 1(b)] and grid pattern [Fig. 1(c)] decrease by adding colored noise. These phenomena can be regarded as *noise-induced order* in convective systems.

Spontaneous oscillation and self-organization play important roles in living systems. Mechanism for extracting essential information from a signal is more important than a perfect reproduction of the signal for living systems. It was clarified by Kai et al. and others that stochastic resonance and stochastic synchronization are utilized for that mechanism [4,5]. For that purpose, living systems may use tunable noise generated within themselves as well as the noise from their surroundings (e.g., thermal noise). In other words, the generated noise is chaos. The most important property of chaos as a noise source is that it has a finite correlation time that corresponds to the inverse of the Lyapunov exponent. The study by Huh et al. provides significant suggestion to us also in this viewpoint.

REFERENCES

[1] L. Gammaitoni, P. Hänggi, P. Jung, and F. Marchesoni, Rev. Mod. Phys. **70**, 223 (1998).

[2] H. Fukuda, H. Nagano, and S. Kai, J. Phys. Soc. Jpn. **72**, 487 (2003).
[3] J.-H. Huh and S. Kai, J. Phys. Soc. Jpn. **83**, 063601 (2014).
[4] T. Mori and S. Kai, Phys. Rev. Lett. **88**, 218101 (2002).
[5] H. Fukuda, J.-I. Kodama, and S. Kai, Biosystems **77**, 41 (2004).

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