

Autonomous motor based on nonlinearity

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October 18, 2013 (Meiji University)

13:10 - 13:50

Ilya Prigogine Dissipative structure (Nobel prize, 1977)

Belousov-Zhabotinsky (BZ) reaction: Nonlinear chemical reaction

Soft matter



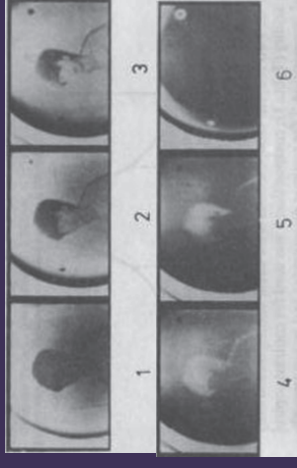
S. Maeda, Y. Hara, T. Sakai, R. Yoshida,
S. Hashimoto, *Adv. Mater.* 2007, **19**,
3480-3484.

Interfacial phenomena

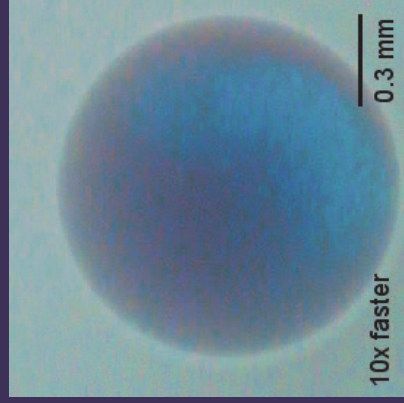
Convection, Interfacial tension



Photo-sensitivity



L. Kunert, K. I. Agradze, V. I. Krinsky,
Nature, 1989, **337**, 244-247.



H. Kitahata et al., *Chem. Lett.*
2012, **41**, 1052-1054.



Mathematical model

Oregonator

Reaction-diffusion



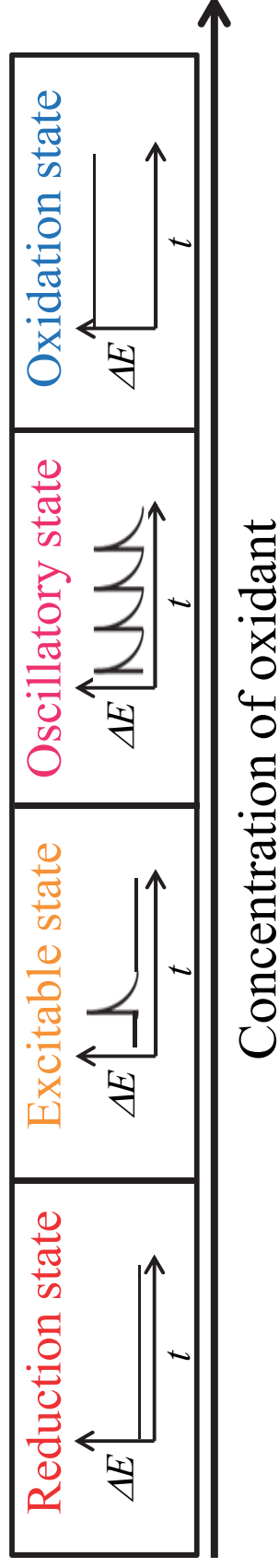
BZ mouse S. Kondo



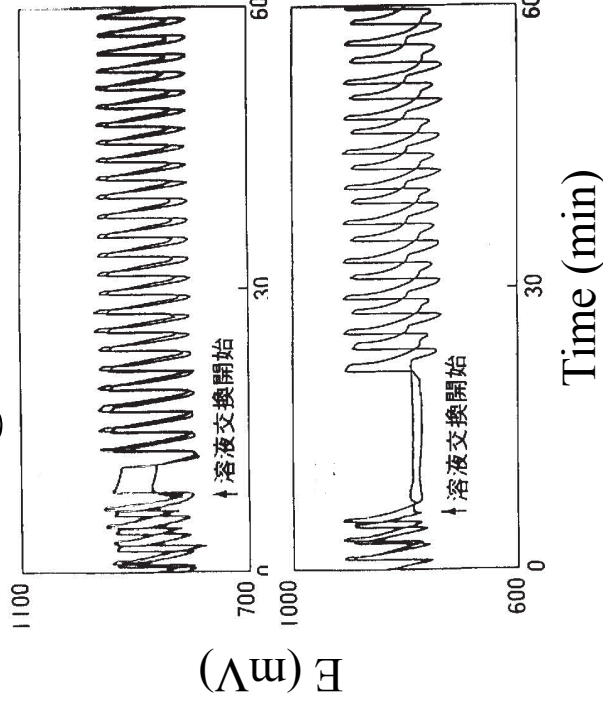
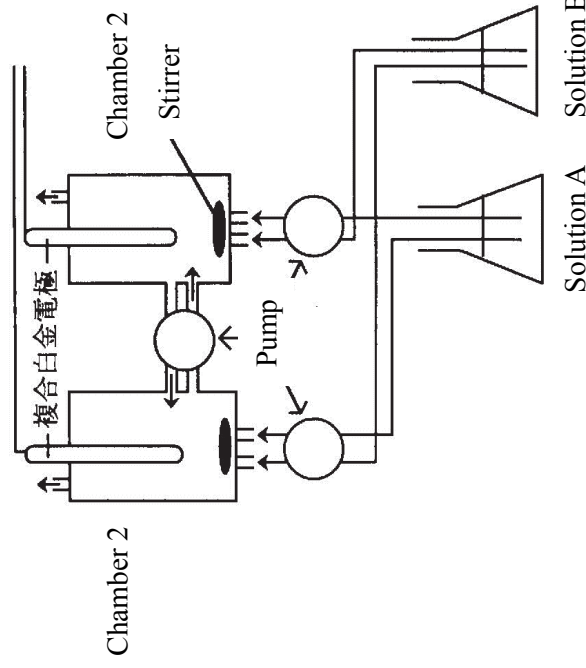
Sakurai et al., *Science*,
2002, **296**, 2009.

What is nonlinearity? (e.g., BZ reaction)

1. Self-oscillation: Repetition between reduction and oxidation
2. Bifurcation: Change in the state as a function of a parameter



3. Synchronization: Phase locking between several oscillators



Exchange flow : High

In-phase

Exchange flow : High

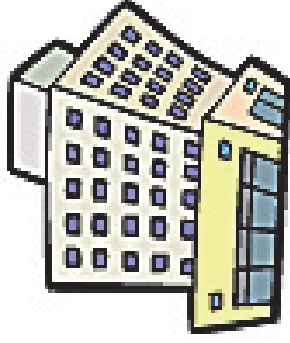
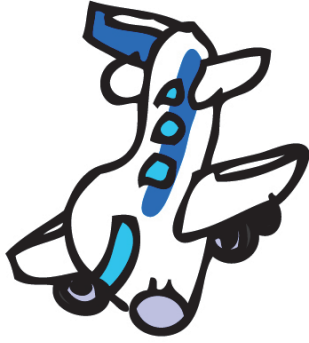
Out-phase

Time (min)

化学と教育(1993年2号)

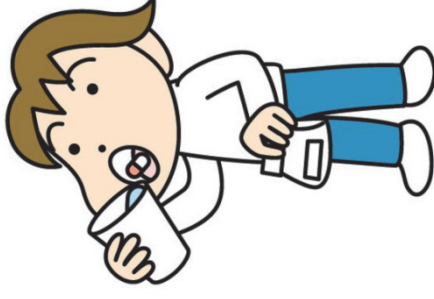
Self-propelled system

Industrial application



Crack or defect of architectures or aircrafts

Medical application



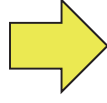
Drug delivery

Previous research on self-propelled systems

Speed and direction of motion controlled by the external force

Miniaturization at nano or micro level

Problem : No autonomy such as chemotaxis in bacteria.



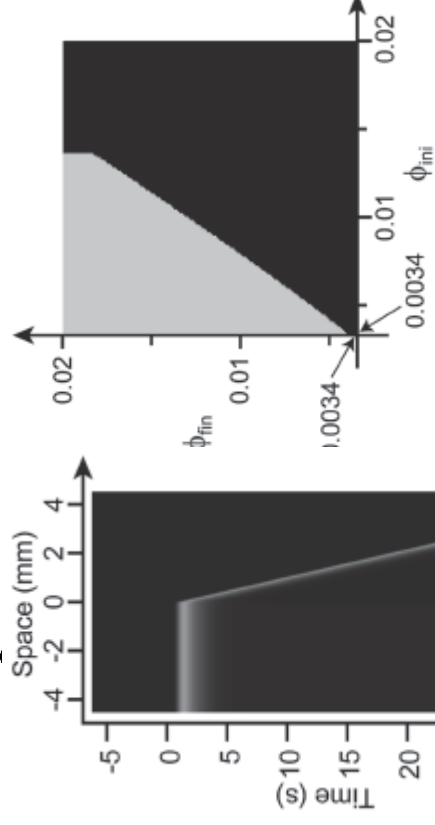
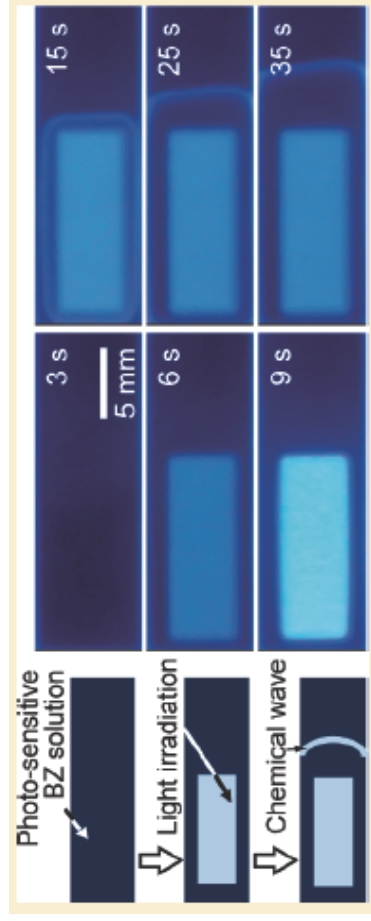
Introduction of nonlinearity which mimics biological phenomena

115, 7406–7412, 2011.

Photoexcited Chemical Wave in the Ruthenium-Catalyzed Belousov – Zhabotinsky Reaction

Satoshi Nakata,^{*,†,‡} Mariko Matsushita,^{‡,§} Taisuke Sato,[†] Nobuhiko J. Suematsu,^{†,||} Hiroyuki Kitahata,[#] Takashi Amemiya,[⊥] and Yoshihito Mori[○]

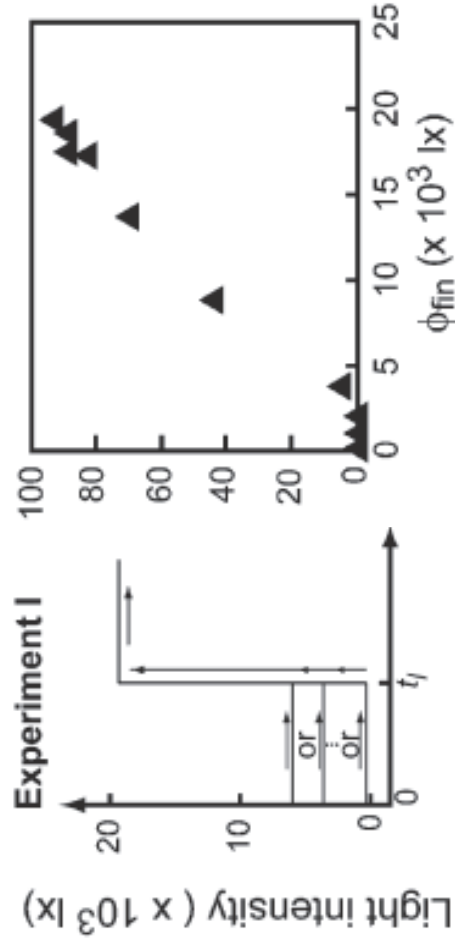
Oregonator model modified for the photosensitive BZ reaction



$$\frac{\partial u}{\partial \tau} = \frac{1}{\varepsilon} [qv - uv + u(1 - u) + p_2 \phi] + D_u \nabla^2 u$$

$$\frac{\partial v}{\partial \tau} = \frac{1}{\varepsilon'} [-qv - uv + fw + p_1 \phi] + D_v \nabla^2 v$$

$$\frac{\partial w}{\partial \tau} = u - w + \left(\frac{p_1}{2} + p_2 \right) \phi + D_w \nabla^2 w$$



Research of BZ system: e.g. my work

There is no information of chemical structures on Oregonator,
i.e., the chemical composition is expressed as X, Y, Z.



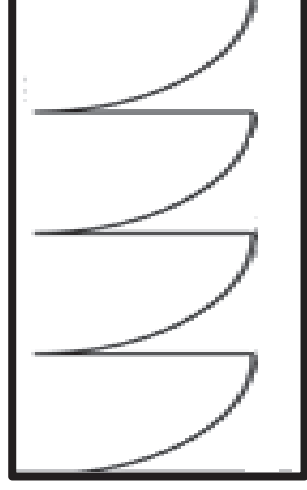
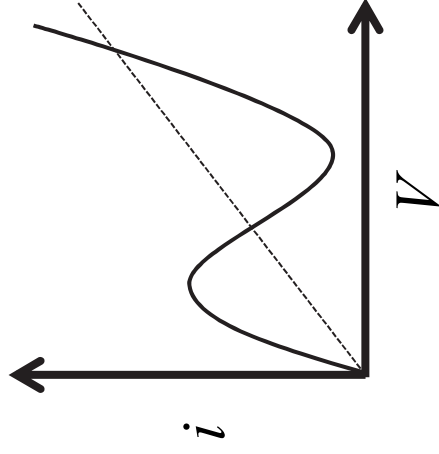
Features of the BZ pattern are independent of the chemical structures.



Creation of a nonlinear phenomenon based on the chemical structure.

How to introduce nonlinearity

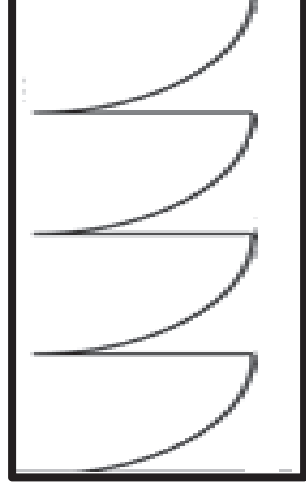
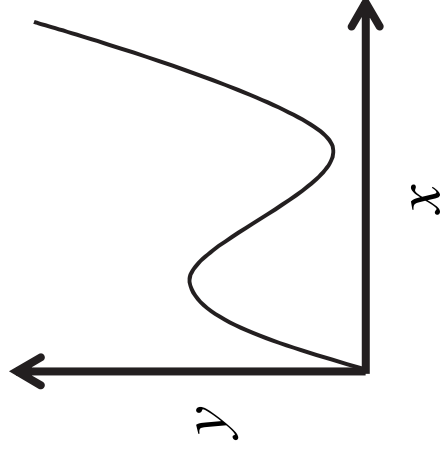
Ezaki diode



Time



Chemical structure



Time

Camphor boat

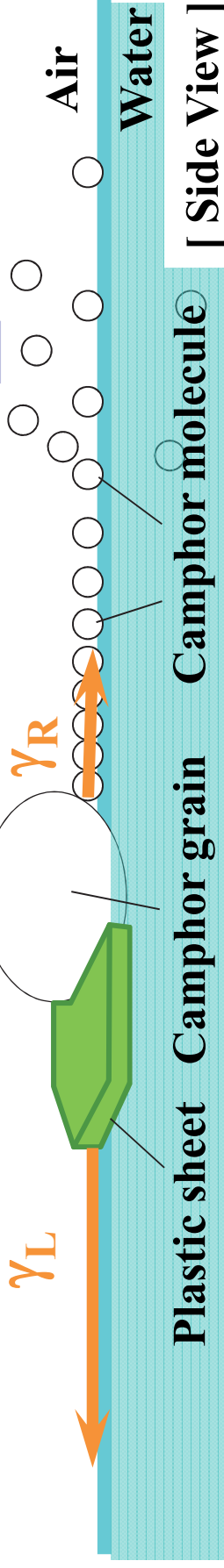
Surface tension

$$\gamma_L > \gamma_R$$

Driving force

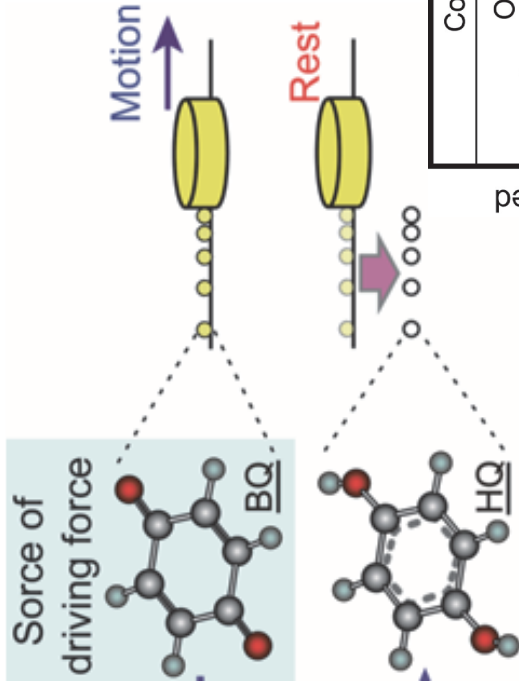
$$F = (\gamma_L - \gamma_R) l$$

Sublimation



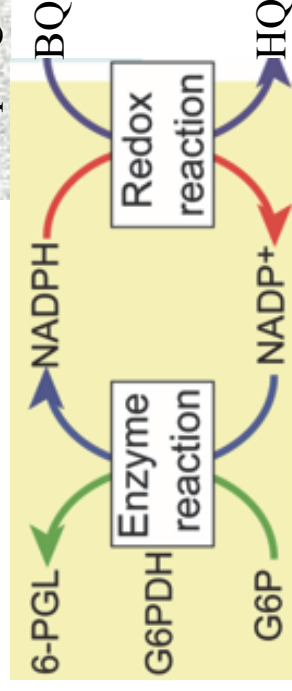
[Side View]

Coupling of chemical reaction



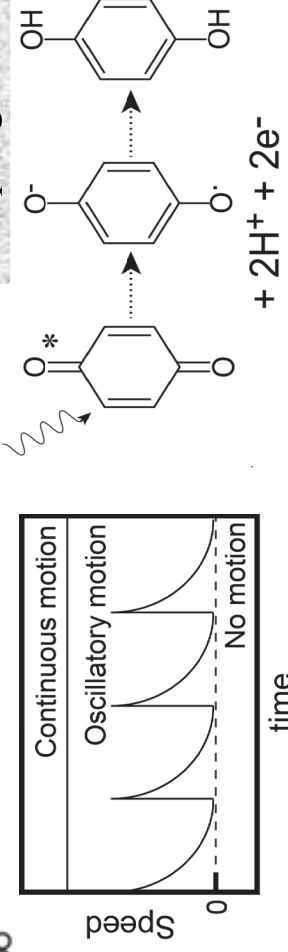
反応拡散の速度バランス
に依存して振動運動が
出現

Coupling with a redox reaction



ChemPhysChem, 2012,
13, 520-524.

UV-irradiation Coupling with a photochemical reaction

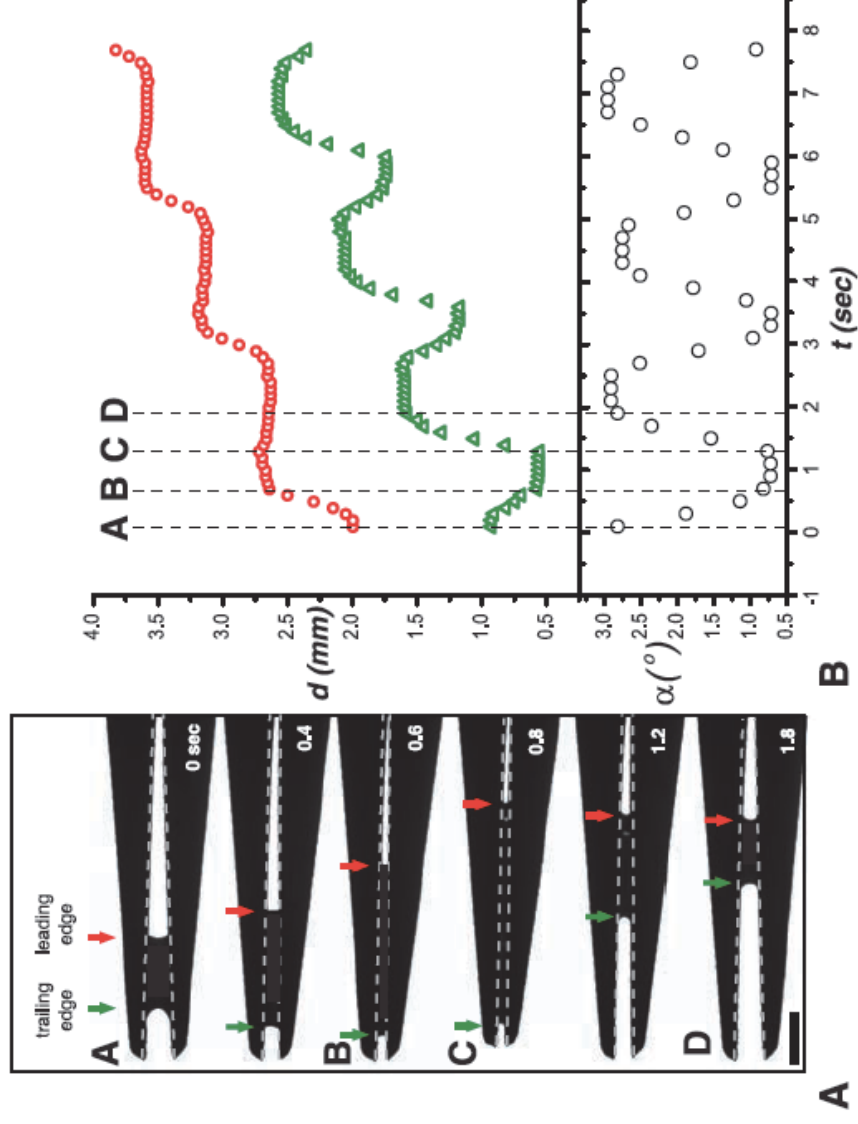
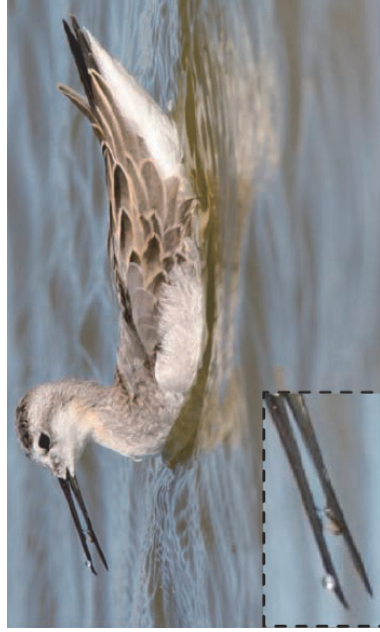


*Physical Chemistry
Chemical Physics*, 2012,
14, 5988-5991.

Surface tension saves Shorebirds.



A fox and a crane (Aesop's Fables)



M. Prakash, D. Quéré, J. W. M. Bush, “Surface Tension Transport of Prey by Feeding Shorebirds: The Capillary Ratchet”, *Science*, **320**, 2008, 931-934.