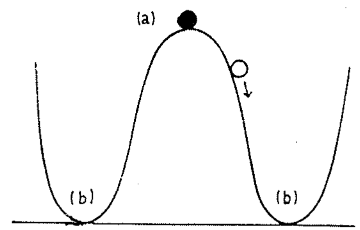
Macroscopic Order Formation, Inflation Mechanism and Entropy Change

Masuo SUZUKI (TUS)



Contents:

1. Purpose of my talk: to review Scaling Theory of M.O. Formation $\rightarrow$ Sato-Guth inflation of universe

   exponential time growing $\Downarrow$ inflation

2. Fluctuation Enhancement Theorem in M.O. Formation

   a) Einstein's theory: $\frac{dv}{dt} = -\gamma v + \eta(t)$ $(\gamma > 0)$

   b) Nonlinear Langevin eq.: $\frac{dx}{dt} = \gamma x - g x^3 + \eta(t)$ ⊛

   — simple but fundamental —

   c) Entropy change: $\sigma_S(t) \equiv \left(\frac{dS}{dt}\right) = \frac{1}{T}\frac{dU(t)}{dt}$,

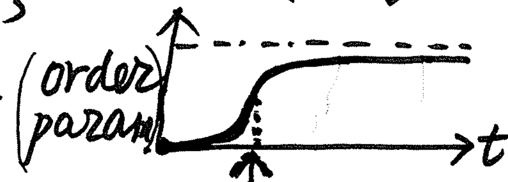
   where $U(t)$ = internal energy; ex. $\hat{U}(x) = -\frac{\gamma}{2}x^2 + \frac{g}{4}x^4$

   $U(t) \equiv \langle \hat{U}(x) \rangle_t$

◎ Scaling solution of Nonlinear Langevin eq. ⊛

○ $$\frac{\langle x^2\rangle_t^{(sc)}}{\langle x^2\rangle_\infty^{(sc)}} = \frac{\tau}{\sqrt{2\pi}}\int_{-\infty}^{\infty}\frac{x^2 e^{-x^2/2}}{1+\tau x^2}\,dx\,; \quad \overbrace{\tau = \frac{g\varepsilon}{\gamma^2}\left(e^{2\gamma t}-1\right)}^{\text{scaling time}} \quad ◎$$

○ $$\frac{\langle x^4\rangle_t^{(sc)}}{\langle x^4\rangle_\infty^{(sc)}} = \frac{\tau^2}{\sqrt{2\pi}}\int_{-\infty}^{\infty}\frac{x^4 e^{-x^2/2}}{(1+\tau x^2)^2}\,dx\,; \quad \langle x^2\rangle_\infty^{(sc)} = \frac{\gamma}{g},\ \langle x^4\rangle_\infty^{(sc)} = \left(\frac{\gamma}{g}\right)^2$$



$\boxed{t_0 = \text{onset time}}$

$$t_0 = \frac{1}{2\gamma}\log\left(\frac{\gamma^2}{g\varepsilon}\right).$$

$\because$ $g\varepsilon \to$ large, $t_0 \to$ small

○ $$\frac{\langle |x|\rangle_t^{(sc)}}{\langle |x|\rangle_\infty^{(sc)}} = \sqrt{\frac{2\tau}{\pi}}\int_0^{\infty}\frac{e^{-x}}{\sqrt{1+2\tau x}}\,dx$$

$\Longrightarrow$ Order Formation

Order parameter

◎ Entropy change: $$\sigma_s(t) = \frac{1}{T}\frac{dU(t)}{dt} = -\frac{\gamma^2}{\sqrt{2\pi}\,g}\int_{-\infty}^{\infty}\frac{\tau x^2 e^{-x^2/2}}{(1+\tau x^2)^3}\,dx$$

negative! <0!

Cf. For ordinary irreversible cases, $\boxed{\text{Hawking black hole's entropy}}$

we have $$\sigma_s(t) \equiv \left(\frac{dS}{dt}\right)_{irr} = \frac{1}{T}\frac{dU(t)}{dt} > 0!$$

◎ entropy production (positive)

Entropy Production and Non-equilibrium Steady States

M.SUZUKI (TUS)

duality

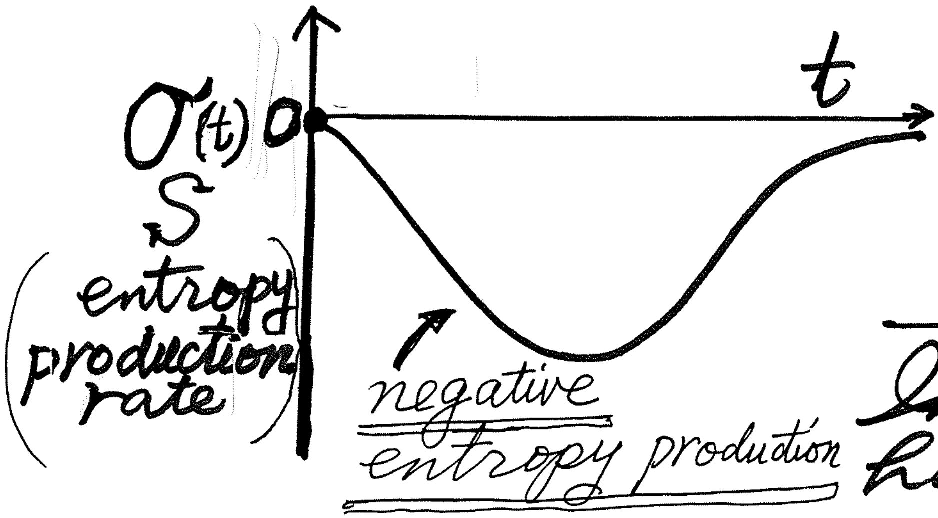
physical phenomena ⟷ life phenomena

(M.S. Prog. Theor. Phys. 56 (1976) 77, 477, 380)

Next, we study <u>Prigogine's principle of minimum entropy production</u>:

$$\frac{d\sigma_S(t)}{dt} = -\frac{\varepsilon \gamma^2 e^{2\gamma t}}{\sqrt{2\pi}} \int_{-\infty}^{\infty} \frac{(1-2\tau x^2) x^2 e^{-x^2/2}}{(1+\tau x^2)^4} dx$$

This yields a counter example:



<u>maximum</u> $\leftrightarrow$ minimum

M. O. Formation — at steady state

In transport phenomena, I have derived the basic formula:

$$\bigcirc \quad \frac{d\sigma_S(t)}{dt} = \frac{F^2}{T} \int_0^\beta d\lambda \, \langle j(-i\hbar\lambda)\, j(t; F) \rangle_0 \longrightarrow 0 \text{ as } t \to \infty$$

external force (F)

(dressed current operator)

at steady state

M.S., Physica A (2011) in press.

New Principle: Principle of

Minimum Integrated Energy Dissipation (MIED)

in Nonlinear Electric Circuits whose resistances depend on the current I: $R_j = R_j(I)$

We introduce the Integrated Energy Dissipation by

$$\sigma_j(I) \equiv \int_0^I R_j(I)\,dI^2 = 2\int_0^I R_j(I)\,I\,dI$$

Principle:

$$\boxed{\sum_j^{all} \sigma_j(I_j) = min}$$

$\Downarrow$

Kirchhoff's second law for any circuit with the current conservation.

(This is an extension of Prigogine's minimum entropy production)

(M. Suzuki, Physica A (2011)...)