REMARKS ON ORIGINS OF BIOMOLECULAR ASYMMETRY

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Abstract. A simple criterion for mirror symmetry breaking in a non-linear chemical system is presented. The selection effect of external asymmetric agents in the process of generation and amplification of biomolecular asymmetry is studied. It is pointed out that this effect will play an important role at bifurcation point, but when the asymmetry of a system has been amplified to a certain extent, a weak asymmetric agent will no longer be able to change the chirality of the system.

There exists mainly two divergent theories on the origins of the asymmetry of biomolecules. One assumes that it is induced by other asymmetric agents such as circularly polarized light, asymmetric adsorption, parity non-conservation in weak interaction, etc. (see, e.g., Thiemann, 1975; Bonner, 1979). The other assumes that it is caused by the so-called spontaneous mirror symmetry breaking, i.e., in certain system the symmetric state may be unstable while the asymmetric state may be stable (see, e.g., Frank, 1953; Seelig, 1971; Decker, 1975). The two theories have their own reasons and difficulties. The asymmetric agents are usually weak in nature, and the asymmetric induced effect is generally small in experiments. As for the models of spontaneous mirror symmetry breaking, two asymmetric stable states with opposite chirality are equally possible, but there exists only one type of chirality for amino acids in proteins and for riboses in nucleic acids. We have tried to combine these two views, and have found that asymmetric agents can play a selection role near the bifurcation point of a nonlinear system which is capable of spontaneous mirror symmetry breaking.

1. A Criterion for Mirror Symmetry Breaking

In order to summarize the various concrete models in the literature, we make use of the chiral polarization (or the enantiomer excess, see, e.g., Morozov, 1979). Let us denote the concentrations of the chiral antipodes in a chemical system by L and D. The chiral polarization is given by $\eta = (L - D)\ (L + D)$. If there is no asymmetric external agent, the change of L and that of D will obey the same rule, i.e., we have

$$\dot{L} = F(L, D) \quad \text{and} \quad \dot{D} = F(D, L)\,, \tag{1}$$

where F is usually a polynomial of L and D. It is not difficult to deduce that

$$\dot{\eta} = \frac{2[DF(L, D) - LF(D, L)]}{(L + D)^2}\,, \tag{2}$$

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the right hand side of which is an odd function of η. Neglecting the higher degree terms, in ordinary cases we have

$$\dot{\eta} = c_1 \eta + c_3 \eta^3, \tag{3}$$

where c_1 and c_3 may be functions of $\xi \equiv L + D$. Morozov (1979) got Equation (3) in a different way. When $c_1 > 0$, the symmetric steady state ($\eta = 0$) is unstable. If we have further $c_3 < 0$, the asymmetric steady states ($\eta = \pm\sqrt{|c_1/c_3|}$) are stable. The case $c_3 < 0$ can be shown by a cusp catastrophe (Figure 1). We can prove that the condition $c_1 > 0$ is equivalent to the condition

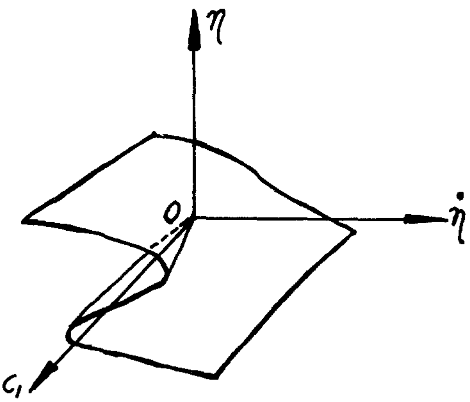

Fig. 1. The cusp catastrophe in the space of η, $\dot{\eta}$, and c_1.

$$c_1 = \left(\frac{\partial}{\partial L} - \frac{\partial}{\partial D}\right) F(L, D)|_{L=D} - \frac{1}{D} F(D, D)|_{L=D} > 0 \tag{4}$$

which is a simple criterion for mirror symmetry breaking and can be easily applied to various models. The criterion has an explicit meaning. Because we can prove that

$$\left(\frac{\partial}{\partial L} - \frac{\partial}{\partial D}\right) F(L, D)|_{L=D} = \lim_{L \to D} \frac{d(L-D)}{dt} \,/\, (L-D) \tag{5}$$

and

$$\frac{1}{D} F(D, D)|_{L=D} = \lim_{L \to D} \frac{d(L+D)}{dt} \,/\, (L+D), \tag{6}$$

Equation (4) says that the relative rate of change of the difference between L and D must be greater than that of their sum in the neighborhood of the symmetric state.

2. Effect of External Asymmetric Agent

If there is an asymmetric external agent, the change of L and that of D will no longer follow the same rule, because the chiral antipodes will have different activation energy under this condition. The influence of circularly polarized light was discussed by Xu and Ding (1981). Thus we have

$$\dot{D} = F_1(D, L), \quad \dot{L} = F_2(L, D), \quad F_1 \neq F_2, \tag{7}$$

or equivalently,

$$\dot{D} = F(D, L) + G(D, L), \quad \dot{L} = F(L, D) - G(L, D), \tag{8}$$

where

$$F(D, L) = [F_1(D, L) + F_2(D, L)]/2, \quad G(D, L) = [F_1(D, L) - F_2(D, L)]/2.$$

Therefore,

$$\dot{\eta} = \frac{2[DF(L, D) - LF(D, L)]}{(L+D)^2} - \frac{2[DG(L, D) + LG(D, L)]}{(L+D)^2}. \tag{9}$$

The first term is an odd function of η, and the second one is an even function of η. In ordinary cases, we have

$$\dot{\eta} = c_1\eta + c_3\eta^3 + \Delta \quad (\Delta \neq 0). \tag{10}$$

When $c_3 < 0$ and c_1 is a little larger than 0, i.e., in the neighborhood of the bifurcation point, the curve of Equation (10) has only one cross-point with the axis $\dot{\eta} = 0$ on the plane of η and $\dot{\eta}$. Hence, there is only one kind of asymmetric stable steady state with definite chirality near the bifurcation point under the effect of external asymmetric agent (Figure 2). Along with the evolution, the coefficient c_1 which is related to the self-replication capacity may increase, and the asymmetry of the system will be amplified.

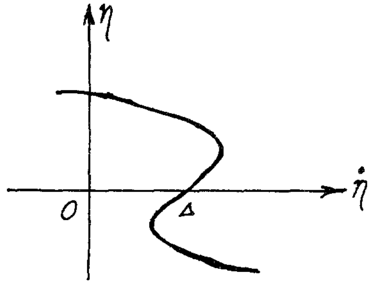

Fig. 2. Under the effect of asymmetric agent there is only one asymmetric stable state near the bifurcation point.

When c_1 is large enough, the asymmetry of the system will be amplified to a certain extent. Although at that time there may be two asymmetric states with opposite chirality, a weak asymmetric agent will no longer be able to change the chirality of the system. This conclusion agrees with facts. The organisms on the Earth have now evolved to such high levels that weak asymmetric agents can by no means change the chirality of biomolecules *in vivo*.

3. Examples

Various models of mirror symmetry breaking were proposed. For brevity, only two of them will be simply examined hereunder.

(1) Decker (1975) has presented a hypercompetitive model, the dynamical equations of which are

$$\frac{\mathrm{d}A}{\mathrm{d}t} = a_4 - 2a_1A(L^{(1+d)} + D^{(1+d)}) - a_3A,$$

$$\frac{\mathrm{d}L}{\mathrm{d}t} = a_1A[(1+b)L^{(1+d)} + (1-b)D^{(1+d)}] - a_3L,$$

$$\frac{\mathrm{d}D}{\mathrm{d}t} = a_1A[(1+b)D^{(1+d)} + (1-b)L^{(1+d)}] - a_3D.$$

According to Equation (4),

$$c_1 = [(\frac{\partial}{\partial L} - \frac{\partial}{\partial D})F(L,D) - \frac{1}{D}F(D,D)]_{L=D} = 2a_1AL^d[b(1+d)-1]|_{L=D},$$

hence the criterion $c_1 > 0$ is equivalent to the condition $b > 1/(1+d)$, which agrees with the result of Decker.

(2) Czégé and Fajszi (1977) presented a counterexample which involves two competitive species and has no asymmetric stable steady state under certain conditions. The dynamical equations of this model may be written as

$$\dot{L} = -a(L^2 + LD) + bL - cD + d,$$
$$\dot{D} = -a(D^2 + LD) + bD - cL + d.$$

We can work out that

$$\dot{\eta} = 2(1 - \frac{d}{L+D})\eta.$$

It corresponds to the case in which the coefficient c_3 in Equation (3) vanishes.

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References

Bonner, W. A.: 1979, in D. C. Walker (ed.) *Origins of Optical Activity in Nature*, p. 5.
Czégé, J. and Fajszi, Cs.: 1977, *Origins of Life* 8, 271.
Decker, P.: 1975, *Origins of Life* 6, 211.
Frank, F. C.: 1953, *Biochim. Biophys. Acta* 11, 459.
Morozov, L. L.: 1979, *Origins of Life* 9, 187.
Seelig, F. F.: 1971, *J. Theor. Biol.* 31, 355, 32, 93.
Thiemann, W.: 1975, *Origins of Life* 6, 475.
Xu, J. H. and Ding, D. F.: 1981, *Scientia Sinica* 24, 997.