§22. Bifurcation and Stability of the Solar Coronal Magneto-Plasma

Kusano, K., Suzuki, Y., Fujie, K., Moriyama, K., Nishikawa, K. (Dept. Mater. Sci., Hiroshima Univ.)

It is widely believed that the solar flare is an event where the free energy accumulated in the coronal magnetic field is catastrophically released. However, the current understanding about the flare mechanism is not yet theoretically unified. We investigate the magnetohydrodynamic (MHD) relaxation process in the solar coronal magnetic field based on the Woltjer-Taylor minimum energy principle [1,2] and the numerical simulations.

First, the general solution of the Woltjer-Taylor minimum energy state is solved in the solar coronal geometry, which is modeled as a rectangular domain. It is found that the solution bifurcates into two different states when the magnetic helicity integral or the geometrical factor defined as the ratio of the height to the width of the domain is satisfactorily increased [3]. Once the solution bifurcates, the stable solution switches from the equilibrium branch connecting to the potential field into a new branch which has a plasmoid structure. Based on this analysis, it is theoretically proposed that the solar flare is a transition process between two different Woltjer-Taylor states, which are generated as a result of the bifurcation.

The theory predicts that the solar flare is triggered when the vertical size of the coronal magnetic loop becomes longer than the horizontal size. The topological structure in the coronal magnetic field must be dramatically changed in the transition process. The result implies that magnetic reconnection must be accompanied by the solar flare in general.

Secondly, we carry out the numerical simulations, in which the dynamic process caused by the photospheric motion is considered [4]. It is revealed that, if the photospheric motion injects the magnetic helicity into the corona, the coronal parameters (the helicity and the geometrical factor) exceed the criteria for the bifurcation, which is theoretically predicted. As a result of it, the instability comes out, and eventually it drives magnetic reconnection which ejects a plasmoid from the coronal loops. The reconnection process can release about a half of the excess energy in the timescale as short as about ten times the characteristic Alfvén transit time. These numerical results are quite consistent not only with our theory but also with the recent observations [5], and they strongly support the validity of the bifurcation theory.

The simulations also clarify the fact that there is some delay between the bifurcation of the minimum energy solution and the trigger of reconnection. Furthermore, it is observed that, as the resistivity decreases, the delay lengthens and the larger excess energy can be stored in the coronal magnetic field until the start of reconnection. These results can be explained by the model that the pre-flare state is a nonlinear phase of instabilities, in which intensive current sheets are being created. Reconnection can be triggered when the intensity of the electric field on the current sheets balances with the inductive electric field in the up-stream regions of the current sheets. Hence, in a smaller resistivity, more intensive current sheets must be created. Finally, we can conclude that, in a very conductive plasma like the solar corona, the bifurcation may be followed by the accumulation of a huge excess energy and by the impulsive release of it, such as observed in the solar flares.

References

1) Woltjer, L.: Proc. Nat. Acad. Sci. USA **44** (1958) 489.

2) Taylor, J.B.: Phys. Rev. Lett. **33** (1974) 1139.

3) Kusano, K., Suzuki, Y., and Nishikawa, K.: Astrophys. J. **441** (1995) 942.

4) Kusano, K., Suzuki, Y., Kubo, H., Miyoshi, T., & Nishikawa, K: Astrophys. J. **433** (1994) 361.

5) Masuda, S., Kosugi, T., Hara, H., Tsuneta, S., and Ogawara, Y.: Nature **371** (1994) 495.