## §31. Chaotic Reconnection in MHD

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Nowadays many researchers share a common understanding that the magnetic reconnection is a fundamental process in the solar flare. For many years, electric resistivity has been considered as a crucial mechanism in the study of the magnetic reconnection, but researchers are gradually realizing that the time scale of reconnection in the solar flare cannot be explained by the traditional resistive reconnection theory. Now it is accepted in most cases that electric resistivity plays a minor role and most of the theoretical works on the reconnection to date deal with the time scale problem. We also consider that the study of the fast magnetic reconnection gives us a clue to clarify a mechanism of the solar flare. Now we shall propose a new fast reconnection mechanism, a resistive "chaotic reconnection" due to mixing of two vortex-current filaments. The mixing is caused by the collision of the two filaments. The term collision means a strong interaction between the two filaments when they mutually approach.

The direct approach to analyzing the fast reconnection mechanism in the solar flare entails three-dimensional full magnetohydrodynamics (MHD) simulation. In our scenario, magnetic flux tubes may be entangled in the magnetically neutral layer in the solar corona, owing to the fast dynamics with the high magnetic Reynolds number. It is, however, too difficult to run the three-dimensional simulations because of the lack of various computer resources and the high magnetic Reynolds number. We consider that a more simplified model is preferable to demonstrate an essential mechanism of the chaotic reconnection as a first step, and decided to use the vortex-current filament model instead of the flux tube model. We, however, presume that essentially the same phenomenon may be demonstrated by our filament model.

In our simulations the two filaments are driven by three types of velocity: the first one is a gravitational drift velocity, the second and third ones are self- and mutually induced velocities by the electric current and vorticity in the filaments. Simulation results show that the filaments are tangled with each other in the collisional region where the strong interaction between them is dominant. Then their configuration is complicated because the local cylindrical symmetry of the magnetic and velocity fields induced by a filament is destroyed by the fields induced by the other filament. In the collisional region, the more asymmetrical initial configuration of the filaments yields the more complicated configuration with time.

Computations of the instantaneous Lyapunov exponents show that when the initial configuration of the filaments is asymmetrical, the exponents are positive after the collision. We find that the complicated configuration of the filaments is brought about by the chaos in the dynamical system. We call the complicated configuration "chaotic configuration" from here on. We consider that the chaotic configuration is induced by the collision of the two vortex-current filaments which are initially positioned asymmetrically in three-dimensional space.

When the configuration of the filaments is chaotic, there are many regions where the filaments overlap. We consider that each overlapping region is equivalent to the traditional diffusion region of the magnetic reconnection. In an overlapping region antiparallel electric currents should cancel each other. Consequently there remains net electric current only and a trajectory of the net electric current may have a different configuration. To obtain a new consistent trajectory of the net electric current, we introduce a three-dimensional space averaging. It is a kind of "coarse-graining", or microscopic mixing of molecules. It is well known that the coarse-graining increases the entropy of a system. This implies that the coarse-graining is an irreversible process. Thus the space averaging is considered to introduce a kind of dissipation process artificially. Tracing the trajectory by the space averaged distribution of the electric current, we obtain a reconnected configuration of the filament. If the effect of electric current on the filament motion is stronger than that of vorticity, the filaments are reconnected following the directions of the electric currents

We introduce a new concept, normalized overlapping volume, to solve the time scale problem of the fast reconnection. The normalized overlapping volume is defined by the volume of the overlapping region calibrated by volume of the nonchaotic one. We assume that a reconnection rate of the chaotic reconnection is proportional to the traditional resistive non-chaotic reconnection rate and the normalized overlapping volume. Simulation results show that the overlapping volume rapidly increases owing to the chaotic dynamics based on ideal MHD, and the reconnection rate becomes sufficiently large because the large overlapping volume enhances the reconnection process. Thus we conclude that the chaotic reconnection is a faster process than the traditional resistive non-chaotic reconnection which has a simple configuration of the magnetic field, for example the Sweet-Parker model, and no effective enhancement by the overlapping volume.

References

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