§18. Magnetic Energy Intensity Transitions and Polarity Reversals in MHD Dynamo

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We performed a computer simulation of magnetohydrodynamic (MHD) dynamo in a rotating spherical shell. The simulation model is as follows: An electrically conducting fluid is confined between two concentric and corotating spheres. The two spheres rotate with the same angular velocity. The temperatures of the inner and outer spheres are kept hot and cold, respectively. The gravity and the temperature difference drive the thermal convection motion. See our recent papers [1]–[3] for the details of the simulation methods and parameters.

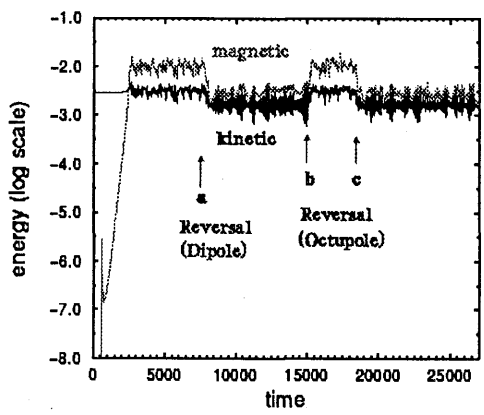

Figure 1: Time development of magnetic and convection kinetic energies.

Fig. 1 shows the time developments of the convection kinetic energy (KE) and the magnetic energy (ME). The ME exponentially grows through the MHD dynamo action. After the nonlinear saturation of the dynamo, the ME and the KE exhibit sudden and intermittent transitions three times. Here, we name the four temporal regions after the nonlinear saturation, demarcated by three transitions (a, b and c in Fig. 1), as NR1 (nonlinear regime 1), NR2, NR3 and NR4. Fig. 1 clearly suggests that there are two stable states; higher ME state (NR1 & NR3) and lower ME state (NR2 & NR4). In the higher ME state, ME is about 5 times larger than KE, while in the lower ME state, ME is the same level as KE.

A dipole moment reversal is observed at the transition time from NR1 to NR2. Fig. 2 shows the meridian cross sections of the azimuthally averaged magnetic field with toroidal (east-west) component (gray scale) and the poloidal component by the field lines. The three panels (A), (B), and (C) are before, during, and after the dipole reversal, respectively. Before the reversal (Fig. 2(A)), when the dipole moment is southward, the toroidal component in the northern hemisphere is westward and it is anti-symmetric about the equator. After the reversal of the dipole moment (Fig. 2(C)), the toroidal component in the northern hemisphere is eastward and it is anti-symmetric about the equator again. Fig. 2 means that the dipole reversal is accompanied by the toroidal component reversal. The coincidental reversal of the toroidal and poloidal fields is consistent with the dipole field generation mechanism by the columnar convection flows explained in [1].

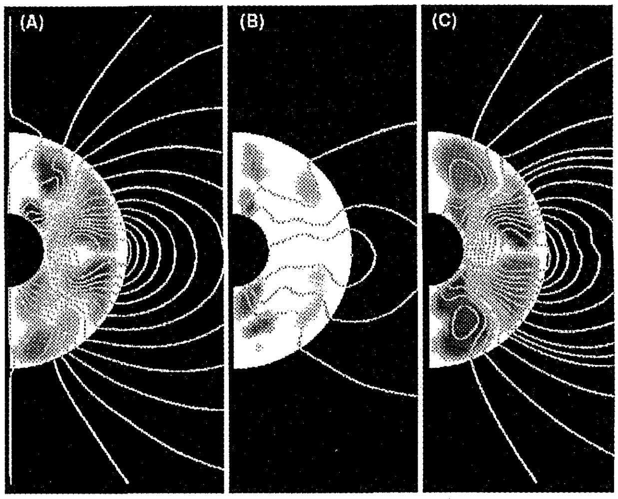

Figure 2: Dipole reversal process in the meridian plane

Within the three transitions of the energy levels in Fig. 1, the dipole reversal takes place only in the first one. Instead, octupole reversals are observed in the second (NR2→NR3) and the third (NR3→NR4) transition.

Paleomagnetic records show that all the dipole reversals observed in the past 4 million years were accompanied by the jumps of the magnetic field amplitude [4]. Furthermore, there were many jumps of the magnetic field amplitude unaccompanied by the dipole reversal, which is also agreeable with our numerical simulation results. Interestingly, our simulation indicates that the magnetic jumps unaccompanying the dipole reversal are correlated with octupole reversals. This would encourage palaeomagnetism scientists to investigate the sedimental records from other aspects.

References

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3) A. Kageyama, Marcia M. Ochi, and T. Sato, *Phys. Rev. Lett.*, to be published

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