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Fluid Mechanics of the Geodynamo

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Fluid dynamical processes in the molten, iron-rich, electrically conducting core sustain Earth's magnetic field. Convection driven by secular cooling and chemical differentiation is the primary energy source for the geodynamo. Earth's rotation imparts helicity to the convection, which amplifies the geomagnetic field, balancing losses from Ohmic dissipation. Both the Ekman and Rossby numbers are very small in the outer core, so the convection is partly aligned with the planetary spin axis, which tends to orient the geomagnetic dipole axis in the north-south direction. The magnetic Reynolds number in the outer core is about 20 times the critical value for sustained dynamo action and the Reynolds number is about 10^7, implying turbulent conditions. Fluctuations in the turbulence induce continuous changes in the geomagnetic field, including occasional polarity reversals. Geomagnetic polarity reversals have occurred about once every 250 kyr on average over the past 5 Myr, the last reversal occurred around 780 ka and there have been several long constant- polarity superchrons. The axial dipole collapses before a reversal, exposing the complex non-dipolar transition field, then the axial dipole is regenerated in the opposite polarity, the entire process lasting 10-20 kyr. Spontaneous polarity reversals have been observed in at least one liquid sodium dynamo experiment. Downward-extrapolated measurements from Earth-orbiting satellites reveal the axial dipole comes mostly from a few high-latitude concentrated flux spots on the core boundary. About 15% of the core boundary has reversed-direction magnetic field, mostly in the southern hemisphere. Proliferation and growth of reversed flux regions are major reasons why the axial dipole is in decline, decreasing at 10 times its free decay rate and suggesting (to some) that the geomagnetic field may be in early stage of a polarity reversal.