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SPINNING FLUIDS, GEOMAGNETISM AND THE EARTH'S DEEP INTERIOR

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Astrophysical and geophysical fluid dynamics is concerned *inter alia* with buoyancy-driven hydrodynamic (HD) and magnetohydrodynamic (MHD) flows in spinning fluids, including the Sun and other stars and the fluid regions of the Earth and other planets. Such flows are dominated dynamically by the action of gyroscopic (Coriolis) forces, and they are exemplified in the case of the Earth by HD flows within the terrestrial atmosphere and oceans and by MHD flow within the electrically-conducting liquid metallic (iron) outer core, where concomitant self-exciting dynamo action generates the main geomagnetic field (1).

The most striking features of the long-term behaviour of the geomagnetic field include reversals in polarity at highly irregular intervals, ranging in duration from *ca.* 0.25 Ma to *ca.* 30 Ma – i.e. very much shorter than the age of the Earth (*ca.* 4500 Ma) but very much longer than the time (*ca.* 0.01 Ma) taken for each reversal to occur. During the past *ca.* 400 Ma there have been two so-called 'superchron' intervals, namely the Permian Superchron from *ca.* 290 Ma to *ca.* 260 Ma ago, when a magnetic compass would have pointed south, and the Cretaceous Superchron from *ca.* 110 Ma to *ca.* 80 Ma ago, when the polarity was the same as it is now (2).

Self-exciting dynamo action involves the amplification of an infinitesimal adventitious magnetic field by the essentially nonlinear process of motional induction. Yet another generic nonlinear process in self-exciting dynamos is the re-distribution of kinetic energy within the system by Lorentz forces (3, 4). Such forces operating within a self-exciting Faraday disk homopolar dynamo loaded with a nonlinear motor can quench the large amplitude fluctuations, some highly chaotic, that would otherwise occur, thereby promoting persistent steady dynamo action (after initial transients have died away) over a very wide range of conditions, with no reversals in the direction of the dynamo current and hence of the magnetic field (3).

This recently-discovered process of nonlinear quenching could be of general theoretical interest in the investigation of nonlinear dynamical systems. If it occurs in the MHD geodynamo then it would provide a firm basis for understanding superchrons as well as other salient features (such as polarity reversal chrons and sub-chrons and polarity excursions) of the long-term behaviour of the geomagnetic field (4). According to this new hypothesis – which has implications for intensity fluctuations of the palaeomagnetic field and could also be tested in due course by analysing the kinetic energy spectrum from the output of valid numerical geodynamo models (5, 6) – those eddies in the core that are driven mainly by Lorentz forces play a crucial role in the inhibition of polarity reversals. Also crucial – and testable – is the possible role in the stimulation of reversals played by changes on geological time scales in the lateral boundary conditions prevailing at the core-mantle boundary (CMB) – where the liquid outer core meets the overlying ‘solid’ mantle – brought about by very slow convection and other dynamical processes affecting the lower mantle (1, 4, 7, 8). Coriolis forces due to the spin of the Earth would render the patterns of core motions, and of the magnetic fields they produce, very sensitive to modest lateral variations in the physical and chemical conditions at the CMB, which techniques of seismology, geodesy, geochemistry, etc. might in due course be capable of resolving with acceptable accuracy (7, 8).

Geodynamo studies thus facilitate the exploitation of a wide range of data in research on the structure, dynamics and evolution of the Earth’s deep interior, about which much remains to be learnt (notwithstanding the great success of the theory of plate tectonics in the investigation of the *outer* layers of the Earth). As in other areas of astrophysical and geophysical fluid dynamics (e.g. dynamical meteorology and oceanography), such work is impeded by the intractability of the governing nonlinear *partial* differential equations expressing the laws of dynamics, thermodynamics and (in the case of MHD) electrodynamics – compounded in this case not only by the lack of detailed geomagnetic observations covering long periods of time but also by the technical difficulties of carrying out laboratory experiments in MHD. So thorough investigations of much simpler but physically realistic self-exciting dynamo systems governed by nonlinear *ordinary* differential continue to play an important if indirect role in studies of the Earth’s deep interior.

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