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David Goss

Nebraska Wesleyan University

Daniel Buller

Nebraska Wesleyan University

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PHYSICS

THE POLAR PATTERN PREDICTOR

David Goss and Daniel Buller

Department of Physics and Astronomy
Nebraska Wesleyan University
Lincoln, Nebraska 68504

A previously overlooked mode of convection in the earth's core has been studied by dye tracing of fluid flow in a laboratory model. The flow is similar in several respects to that in an atmospheric low pressure system.

† † †

Several models of the dynamo that generates the magnetic field of the earth are based on the assumption of a convective flow in the liquid portion of the earth's outer core that possesses non-vanishing helicity (Busse, 1978; Moffatt, 1978). Helicity is a measure of the strength of flow and its twist: the helicity density is the scalar product of the velocity of the flow and its vorticity. The vorticity is the curl of the velocity and thus gives a measure of the twist around the direction of motion. A laboratory model, the polar pattern predictor, that demonstrates several qualitative flow features, including helicity expected to be associated with the flow of the geodynamo, is exhibited here.

Busse (1975 and 1976) performed quasilinear calculations to indicate the probable form of convective motion in the earth's interior that might be associated with the geodynamo. Busse and Carrigan (1976) actually modeled the flow in a rotating annulus and established the presence of the cylindrical convective rolls. These rolls are the dominant feature in the circulation outside a cylinder inscribing the solid inner core. However, such flows do not have net helicity, and second-order effects, such as Ekman suction, are required to give secondary flows capable of dynamo action (Busse, 1970, 1973, and 1976; Moffatt, 1978:313-318).

We focus attention on the flow in the region within the cylinder inscribing the solid inner core of the earth. Away from the axis of rotation, the columnar flow predicted by the

Taylor-Proudman theorem (Greenspan, 1968) and the Taylor constraint (Taylor, 1963) would be expected to dominate beyond a certain radius. However, convection should be important somewhere within the region. A rising column of fluid should develop along the polar axis along which fluid would ascend while rotating, similar to an atmospheric low pressure area. This was shown to be the case. Because the motion is dominated by the columnar behavior, it is anticipated that convection will begin at the point within the shortest distance between the spherical surfaces along a path parallel to the axis of rotation; this is the rotation axis (Z axis) for the spherical annuli and our apparatus. Inward flow to an ascending column is deviated by the Coriolis term to give the azimuthal component of the helical flow.

The example of Busse and Carrigan (1976) in reversing the direction of the thermal gradient and the effective gravity relative to conditions in the earth's core was followed. Our apparatus is shown in Figure 1. A copper hemisphere of outside radius 5.08 cm (2.0 inches) is attached to an acrylic cylinder with the same radius inside; an acrylic end-cap has an inside spherical surface of radius 10.2 cm (4.0 inches) machined concentric with the hemisphere. The entire system is driven by a Cenco variable-speed rotation apparatus, mounted upside down on the underside of a bench. The upper part of the hollow copper hemisphere is filled with a mixture of water and alcohol, frozen solid. By directing a heat lamp at the flat face of the end-cap, thermal gradients of 50 to 60 C can be maintained for periods of a few minutes. The fluid in the flow region is tap water.

The ascending column of warmer fluid is shown outlined by a dye tracer in Figure 1. The azimuthal rotation of the column with respect to the container appears to be in the same direction as the rotation of the container with respect to the

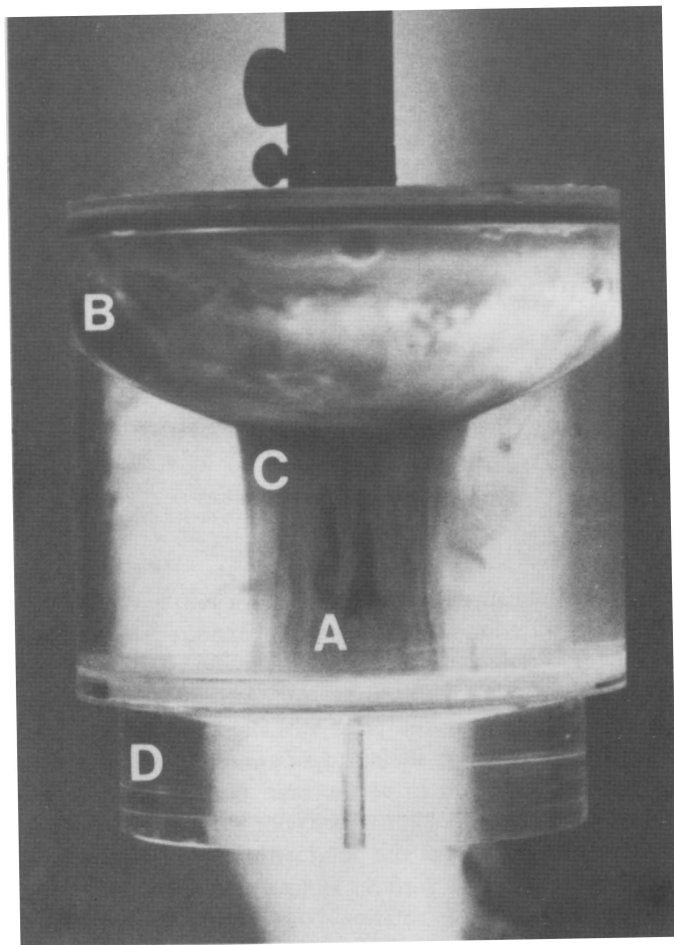


FIGURE 1. The polar pattern predictor. Two dye traces (A) ascend toward the cooled copper hemisphere (B). The outline of the upward convective region (C) is shown faintly with dye. The heat-absorbing acrylic end-cap (D) is at the base. Note the spiral shape of the dye tendrils that confirms the rotation about the symmetry axis with respect to the container.

laboratory, and this continues as the warm fluid reaches the hemisphere, cools, and begins to descend. Descending fluid thus tends to have a helicity opposite that of the ascending fluid; however, if the azimuthal velocity goes as the reciprocal of the distance R from the rotation axis, no contribution to the vorticity (and hence the helicity) results. This behavior is typical of models of atmospheric cyclonic flow, where the main contribution to the vorticity comes from the more rapidly moving inner core. Such a flow has net helicity.

Dye tracers were observed in various stages of the flow path; some near the wall descended to complete the convection cycle as outlined. Because of variation in the rotation rate

and the range of motions possible in such a container, it was difficult to determine unambiguously all of the features of the convective flow. The length of time during which the coolant remains cold enough to ensure a stable temperature gradient was also restrictive.

Replacement of the Taylor constraint (Taylor, 1963) of no-flux transmission through cylindrical surfaces concentric with the rotation axis by a physical boundary that does this is defensible for modeling purposes. Results of Busse and Carrigan (1976) and our previous modeling indicate that there actually is very little coupling between the regions external and internal to the cylinder inscribing the inner sphere, particularly on the time scale used in these experiments. The tantalizing question of whether such coupling could lead to models of geomagnetic reversals *via* the analogy between the oppositely rotating polar flows and the Rikitake coupled disk dynamos (Rikitake, 1958; Moffatt, 1978:318 *et seq.*) is left open.

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REFERENCES

- Busse, F. H. 1970. Thermal instabilities in rapidly rotating systems. *Journal of Fluid Mechanics*, 44:441–460.
- _____. 1973. Generation of magnetic fields by convection. *Journal of Fluid Mechanics*, 57:529–544.
- _____. 1975. A model of the geodynamo. *Geophysical Journal of the Royal Astronomical Society*, 42:437–459.
- _____. 1976. Generation of planetary magnetism by convection. *Physics of Earth and Planetary Interiors*, 12:350–358.
- _____. 1978. Magnetohydrodynamics of the earth's dynamo. *Annual Review of Fluid Mechanics*, 10:435–462.
- _____, and C. R. Carrigan. 1976. Laboratory simulation of thermal convection in rotating planets and stars. *Science*, 191:81–83.
- Greenspan, H. 1968. *The theory of rotating fluids*. Cambridge, United Kingdom, Cambridge University Press: 328p.
- Moffatt, H. K. 1978. *Magnetic field generation in electrically*

conducting fluids. Cambridge, United Kingdom, Cambridge University Press: 343p.

Rikitake, T. 1958. Oscillations of a system of disk dynamos. *Proceedings of the Cambridge Philosophical Society*, 54: 89-105.

Taylor, J. B. 1963. The magneto-hydrodynamics of a rotating fluid and the earth's dynamo problem. *Proceedings of the Royal Society of London, Section A*, 274(1357): 274-283.