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Flow and magnetic instabilities in the spherical Couette system

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The interaction between shear flow and magnetic instabilities plays an important role for the dynamics of many celestial bodies ranging from galaxies to the dynamo regions of planets. Several laboratory and numerical experiments have been devoted to studying this interaction. We have used numerical simulation to explore the flow and dynamo action in a viscous and electrically conducting fluid between two differentially rotating spheres, the spherical Couette system. The ration rate of inner and outer spheres as well as the magnetic Prandtl number were varied in order to understand the dynamics. The solutions for slowly rotating (Ekman number » 1) and fast rotating outer spheres (Ekman number « 1) differ significantly with an interesting transition regime. For slow rotating outer spheres and slow rotating inner spheres viscous forces dominate and the fluid simply sticks to the inner boundary. This changes when the inner sphere rotation rate increases. Meridional circulation creates a cusp of fast rotating material attached to the inner sphere which ultimately becomes instable and non-axisymmetric flow instabilities arise. These can drive a dynamo for magnetic Prandtl numbers of 0.5 or larger. For a fast rotating outer sphere and slow rotating inner sphere the system obeys the axisymmetric Taylor/Stewardson solution where the fluid sticks to the outer boundary outside the tangent cylinder (TC), an imaginary surface attached to the inner core equator and aligned with the rotation axis. Inside the TC the fluid rotates with an rate intermediate between that of the outer and inner spheres. The Stewardson layer that matches the flow inside and outside the TC becomes instable when the differential rotation between inner and outer boundary is increased, once more leading to non-axisymmetric flows. These instabilities differ for prograde and retrograde rotating inner boundaries unless the outer boundary rotating is very fast (E$\leq 10^{-6}$). The time behavior changes from drifting to oscillatory and ultimately chaotic if the differential rotation is increased further. As in the case for slow rotating outer boundaries, the instabilities can drive dynamos. The lowest magnetic Prandtl number we were able to reach so far is 0.05 at an Ekman number of E=10^{-4}. Lower values may be possible, but we are limited by our computer resources here. The results suggests that dynamo experiments based on this setup may indeed succeed to produce self excited dynamo action.