

Magnetic Instabilities Driven by Sheared Toroidal and Poloidal Flows in the limit of $B=0$

Grant No. DE-FG02-98ER54477

Final Report

This is the final report summarizing activity on DoE Grant No. DE-FG02-98ER54477. The grant was used for startup activity in an experiment designed to address key questions related to the MHD dynamo, a process by which kinetic energy in flowing, conducting fluids can be spontaneously converted into magnetic energy. In addition to this grant, a large fraction of the support for the Madison Dynamo Experiment also comes from NSF in the form of a CAREER award, and from the David and Lucille Packard Foundation. Dynamos have been invoked to explain the magnetic fields associated with planets, stars and other astrophysical bodies. The experiment consists primarily of a 1 m diameter sphere of liquid sodium with flows driven by mechanical propellers.

1. Summary of work done on grant.

During the duration of the grant, we have made significant progress towards establishing a laboratory for studying current and magnetic field generation in MHD systems (dynamo action). Progress has occurred in three areas: (a) theoretical understanding and numerical modeling of the dynamo experiment, (b) design and construction of the sodium MHD laboratory and dynamo apparatus, and (c) water experiments simulating the hydrodynamics of the MHD experiment.

- (a) We have made significant progress in modeling the dynamo experiment. An eigenmode code has been written for determining the linear stability and structure of magnetic eigenmodes given a velocity field in a sphere. This code has been used to search for velocity fields with low values of magnetic Reynolds numbers (a dimensionless number which quantifies the onset of magnetic instability in dynamo theory and is equal to the product of conductivity times velocity times device size $Rm = \mu_0 \sigma V_0 a$); small magnetic Reynolds numbers translates into more easily achieved experimental conditions for an experiment. We have found velocity fields which will lead to dynamo action at Rm values which are two times smaller than found previously for the sphere.

The eigenmode code can also be used in to simulate the linear response of the device to applied magnetic fields. The code has been used to simulate an experiment in which a external dipole magnetic field is applied to the experiment, converted to the toroidal direction (east-west in a sphere), and amplified, a process known as the ω -effect in geodynamo literature. We expect to have fields 100 times the applied field produced by sodium flows, demonstrating conversion of kinetic energy into magnetic energy, part of the dynamo process. Comparisons of measurements with the predictions of this code will be a critical part of our experimental approach.

Flows are measured in a water experiment with identical dimensionless parameters (Reynolds number Re) and used a input to the code. The magnetic response will be measured and compared with the predicted response. Differences can be attributed to the role that turbulence plays in current generation.

- (b) Velocity fields have been produced and measured in a full size water experiment which are topologically identical to flows required for dynamo action and can lead to dynamo action. Water and sodium have identical viscosities and mass densities; therefore the water experiment has identical flows to those of sodium in the absence of electromagnetic forces. The results of these studies are propeller designs which produce dynamo flow geometries. Turbulence levels have been measured and are likely to play an important role in the flux diffusion, and result in an anomalous resistivity.

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We have no objection from a patent standpoint to the publication or dissemination of this material.

Mark P. Drorazale Aug 25 2000

Office of Intellectual
Property Counsel
DOE Field Office, Chicago

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- (c) A sodium laboratory has been constructed. This includes a device hall, renovated by the University and includes smoke handling equipment, major electrical upgrades, and mechanical support for the experiment. The sodium holding tank and the experimental vessel have been designed and constructed. Sodium is on site, donated by Argonne National Laboratory. Sodium seals have been designed and procured. The motors for driving the propellers are installed, and the final assembly of the experiment is underway.

A substantial amount of sodium handling equipment has been transferred from the ETEC laboratory, run by Boeing for the DoE to the UW. The equipment includes heaters, thermocouples, valves, thermowells, pressure transducers, etc. All of the equipment will be of great use to the dynamo project.

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