Magnetohydrodynamics and Turbulence (M24)

Alexander Schekochihin

It is sometimes said that turbulence is the last great unsolved problem of classical physics. MHD turbulence, or turbulence of conducting fluid, exists in many physical systems: liquid-metal experiments, fusion devices, the Earth's interior and virtually all astrophysical plasmas from stars to galaxies and galaxy clusters. Many observed properties of astrophysical bodies (and, in some cases, their very existence) cannot be explained without recourse to some model of turbulence and turbulent transport in the constituent plasma. Thus, one could view the theory of MHD turbulence as a theory of the fundamental properties of luminous matter that makes up large-scale astrophysical bodies. MHD turbulence is an area of very active current research, motivated by the recent rapid and simultaneous progress in astrophysical observations (especially of the solar photosphere, interstellar and intracluster medium), high-resolution numerical simulations, and liquid-metal laboratory experiments.

The aim of this course is to first provide a basic introduction both to the laws of fluid motion in conducting media (magnetohydrodynamics) and to the fundamental theory of turbulence, and then to bring together these two subjects in presenting the modern state of the MHD turbulence theory. Thus, the course will consist of three parts (the number of lectures to be devoted to each, as given below, is approximate):

I. Hydrodynamic Turbulence (5 lectures). This will be an introduction to the fundamental theory of homogeneous isotropic turbulence: Kolmogorov's 1941 dimensional theory, correlation functions (kinematics of turbulence), exact results (the 4/5 law), modern theory of intermittency (the She-Lévêque model). Some lements of scalar turbulence and mixing will also be covered (Obukhov-Corrsin and Batchelor dimensional theories). Further topics in turbulence will be treated in "Hydrodynamic Turbulence" (Dr P. Davidson, L16) — there will be very little overlap with this course (no more than 3 lectures).

II. Magnetohydrodynamics (6 lectures). I will cover a set of basic topics that are necessary for someone with no previous experience of MHD to understand the 3rd part of the course: MHD equations, Lagrangian MHD, flux freezing, conservation laws, magnetic helicity, MHD waves (Alfvén waves). Further topics in MHD (compressible MHD, instabilities, shocks etc.) will be treated in "Astrophysical Fluid Dynamics" (Dr G. Ogilvie, M24).

III. MHD Turbulence (13 lectures). Dimensional theories of MHD turbulence in the presence of a mean magnetic field (Alfvén-wave phenomenologies), weak turbulence theory, intermittency models, generation of small-scale magnetic fluctuations by turbulence (the small-scale dynamo), exact results and the phenomenology of the isotropic MHD turbulence (no mean field), an introduction to turbulence in some astrophysical contexts: solar wind, interstellar medium, accretion discs, clusters of galaxies. Further aspects of MHD dynamos — especially antidynamo theorems, mean-field dynamo theory, solar and geodynamos — will be treated in "Stellar and Planetary Magnetic Fields" (Prof M. Proctor, L24).

Desirable Previous Knowledge

This course is suitable both for astrophysicists and fluid dynamicists. It will not require any previous knowledge of astrophysics or MHD. Some basic familiarity with the equations of fluid dynamics and of electricity and magnetism will be helpful.

Reading

1. L. D. Landau and E. M. Lifschitz, *Course of Theoretical Physics,* vol. 6: *Fluid Mechanics* (Butterworth-Heinemann, 1995), §§33–34.

2. P. A. Davidson, *An Introduction to Magnetohydrodynamics* (CUP, 2001).

3. P. A. Sturrock, *Plasma Physics* (CUP, 1994), §§12–17.

4. R. M. Kulsrud, *Plasma Physics for Astrophysics* (Princeton University Press, 2005).

5. D. Biskamp, *Magnetohydrodynamic Turbulence* (CUP, 2003).