Magnetohydrodynamics and Turbulence (L24)

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 objects (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, in astrophysics, one could view MHD turbulence theory as a theory of the fundamental properties of matter that large-scale objects are made of. 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 and interstellar medium), massively parallel numerical simulations, and liquid-metal laboratory experiments.

The aim of this course is to provide a basic introduction both to the laws of fluid motion in conducting media (magnetohydrodynamics) and to the fundamental theory of turbulence. Finally, these two subjects will be brought together in an overview of the modern state of the MHD turbulence theory. Thus, the course will consist of three parts:

I. Magnetohydrodynamics. MHD equations, flux freezing, conservation laws, magnetic helicity, MHD equilibrium, force-free solutions, stability, MHD waves (Alfvén waves), MHD instabilities. More advanced topics will include reduced MHD (MHD in the presence of a strong external magnetic field), resistive instabilities (tearing mode), magnetic reconnection. The MHD instabilities in rotating shear flows will be treated in "Accretion Discs" (Dr G. Ogilvie, Lent Term).

II. Hydrodynamic Turbulence. Kolmogorov's dimensional theory of turbulence and exact results will be covered in detail, followed by an overview of the modern state of turbulence research, including closure schemes, intermittency and scalar turbulence (turbulent mixing).

III. MHD Turbulence. Dimensional theories (Alfvén-wave phenomenologies), exact results, an overview of closures, weak turbulence, and intermittency models. The generation of small-scale magnetic fluctuations by turbulence (the small-scale dynamo) will be studied in some detail. Other aspects of MHD dynamos (especially antidynamo theorems, mean-field dynamo, solar and geodynamos) will be treated in "Dynamo Theory" (Prof. M. Proctor, Easter Term).

Desirable Previous Knowledge

This course is suitable both for astrophysicists and fluid dynamicists. It will not require any previous knowledge of astrophysics and will present MHD and turbulence as areas of theoretical physics. Some basic knowledge of fluid dynamics and electricity and magnetism will be helpful. Having followed "Astrophysical Fluid Dynamics" (Prof. J. Pringle, Michaelmas Term) can be useful, but is not a prerequisite.

Reading

1. T. G. Cowling, *Magnetohydrodynamics* (Adam Hilger Ltd, 1976).
2. P. A. Sturrock, *Plasma Physics* (CUP, 1994), §§12–17.
3. P. A. Davidson, *An Introduction to Magnetohydrodynamics* (CUP, 2001).

4. G. K. Batchelor, *The Theory of Homogeneous Turbulence* (CUP, 1982).

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

6. U. Frisch, *Turbulence. The Legacy of A. N. Kolmogorov* (CUP, 1995).

7. P. A. Davidson, *Turbulence — An Introduction for Scientists and Engineers* (OUP, 2004).

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