§28. Dynamos and MHD Theory of Turbulence Suppression

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In this review work [1], characteristics of electrically-conducting media are reviewed from the macroscopic viewpoint based on the mean-field magnetohydrodynamics. The themes covered in this review range from the generation mechanism of stellar magnetic fields (dynamo) to transport properties in fusion. The primary concern here is to see the characteristics common to these apparently different phenomena, within the framework of the mean-field theory. Owing to the intrinsic limitation of the approach, the present discussions are limited more or less to specific aspects of phenomena. They are supplemented with the reference to theoretical, numerical, and observational approaches intrinsic to each theme. In the description of dynamo phenomena, an emphasis is put on the cross-helicity dynamo. The electromotive force is expressed as $\boldsymbol{E}_T \equiv \langle \boldsymbol{u}' \times \boldsymbol{B}' \rangle = \alpha \bar{\boldsymbol{B}} - \beta \bar{\boldsymbol{j}} + \gamma \bar{\boldsymbol{\omega}}$ (' denotes the turbulent part and the over-bar denotes the mean field.) The coefficient γ represents the cross helicity dynamo. Features common to the stellar magnetic-field generation and the rotational-motion drive in toroidal plasmas are illustrated on this basis. This review covers the following issues:

1. Introduction
2. Explored phenomena and mean-field approach
2.1. Planetary magnetic fields
2.1.1. Dipole fields of planets
2.1.2. Solar magnetic field
2.1.3. Comparison of geomagnetic field and solar magnetic field
2.2. Spontaneous magnetic-field generation in toroidal plasmas
2.3. Electromagnetic flow generation and accretion disks
2.3.1. Accretion disk
2.3.2. Transport barriers in tokamaks
2.4. Stellar dynamo and structure formation in toroidal plasmas
2.5. Mean-field magnetohydrodynamic approach
3. Magnetohydrodynamic equations
3.1. Two-fluid equations
3.2. One-fluid equations
3.2.1. Variable-density flow
3.2.2. Constant-density flow
3.3. Electrohydrodynamics
4. Mean-field magnetohydrodynamics
4.1. Constant-density hydrodynamic equations
4.1.1. Turbulent-viscosity representation
4.1.2. Nonlinear algebraic representation
4.1.3. Turbulent heat flux
4.2. One-fluid constant-density magnetohydrodynamic equations
4.2.1. Algebraic representations for turbulent fluxes
4.2.2. Heuristic explanation for α , β and γ effects
4.2.3. Physical implications of turbulent-flux effects
4.2.4. Turbulence equations for determining dynamo coefficients
4.2.5. Classification of mean-field dynamos
4.3. Variable-density electrohydrodynamic equations
4.3.1. Mass-weighted averaging
4.3.2. Algebraic representations for turbulent fluxes
5. Spherical-shell dynamo
5.1. One-fluid MHD model of stellar dynamos
5.1.1. Fundamental equations
5.1.2. Nondimensional parameters characterizing MHD flows
5.1.3. Taylor-Proudman theorem and Busse column
5.2. Representative findings by computer experiments
5.2.1. Typical parameters for simulation
5.2.2. Convection column and magnetic field
5.2.3. Partition of energy
5.2.4. Reversal of polarity
5.2.5. Other prominent features
5.3. Mean-field dynamo
5.3.1. Alpha dynamo
5.3.1.1. Two typical dynamo processes
5.3.1.2. Examination of kinematic dynamo
5.3.2. Alpha/cross-helicity dynamo
5.3.2.1. Relevance to geodynamo
5.3.2.2. Relevance to solar dynamo
5.3.2.3. Selection of structure
6. Flow generation by electromagnetic effects
6.1. Accretion disks
6.1.1. Computer simulation of bipolar jets
6.1.2. Mean-field approach to jet formation and collimation
6.1.2.1. Accretion-disk magnetic field
6.1.2.2. Ejection of jets
6.1.3. Anomalous diffusion of angular momentum
6.2. Rotation drive of fusion plasmas
6.2.1. Flows in H modes and plasma responses
6.2.2. Mean-field MHD picture
6.2.2.1. Zonal flow of semi-micro scales
6.2.2.2. Interference of flow with magnetic field
7. Electromagnetic effects on turbulent transports: Towards consistency
7.1. Effects of generated magnetic field on dynamo coefficients
7.1.1. Suppression of α by generated magnetic field
7.1.2. Suppression of β by generated magnetic field
7.1.3. Note on γ dynamo
7.2. Suppression of turbulent transport by generated flows
7.2.1. Increase in nonlinear damping by sheared flow
7.2.2. Reduction of turbulence production within the framework of mean-field MHD
7.2.2.1. Suppression of velocity fluctuations
7.2.2.2. Heat-flux suppression and countergradient diffusion
7.3. Magnetic-field effects on off-diagonal elements of heat-transport matrix
7.4. On variational principles
8. Summary

[1] A. Yoshizawa, S.-I. Itoh, K. Itoh, N. Yokoi; Plasma Phys. Contr. Fusion **46** (2004) R25